CONTROL

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A TECHNICAL JOURNAL FOR DESIGNERS AND USERS OF ELECTRICAL, ELECTRONIC, HYDRAULIC, MECHANICAL AND PNEUMATIC CONTROL SYSTEMS AND INSTRUMENTATION

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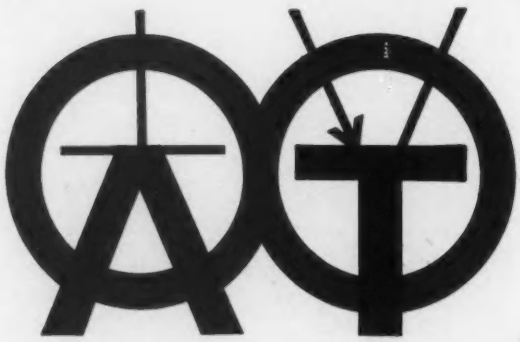

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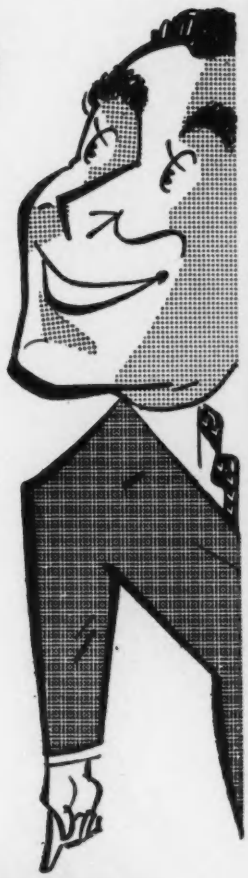

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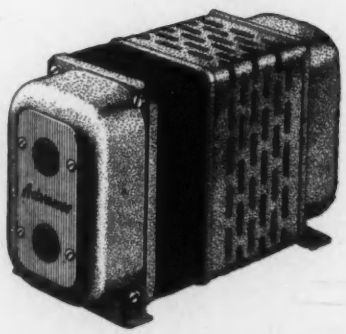

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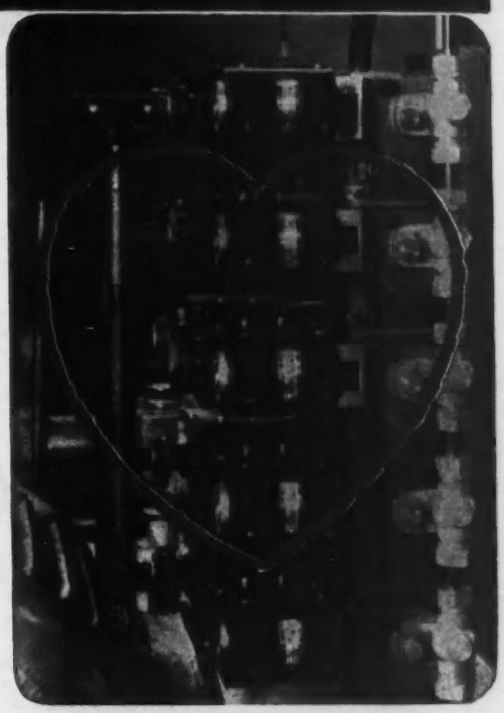

Bank of Westool Solenoids operating hydraulic valves. Photograph by courtesy of Towler Brothers Ltd, Leeds.

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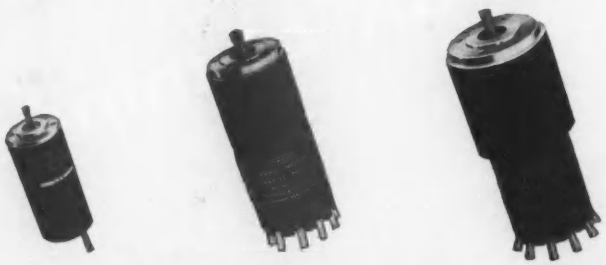

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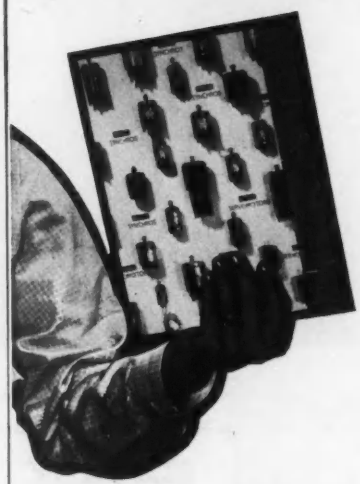

This revised issue of the Muirhead Synchro Broadsheet is available to all those interested in servo engineering. Prepared for easy reference, it presents the brief specifications of Muirhead Control Transmitters and Receivers; Motor Tachometers and Tachometer Generators; Two-Phase Servomotors and Resolvers and Linvars in Standard Synchro frame sizes. It is available without charge and will be sent upon request.

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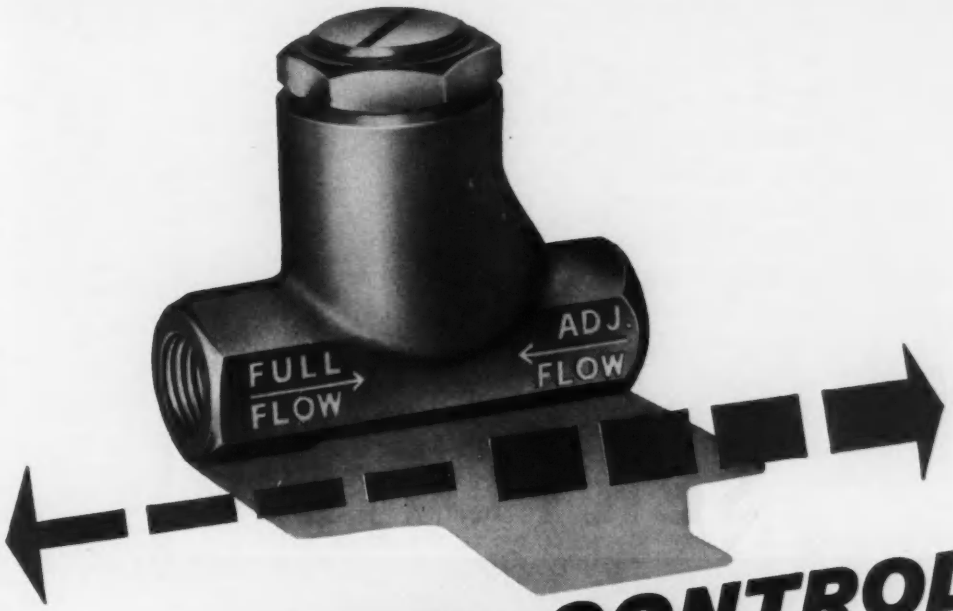

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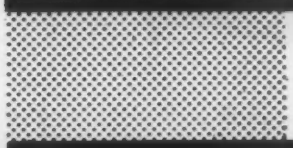

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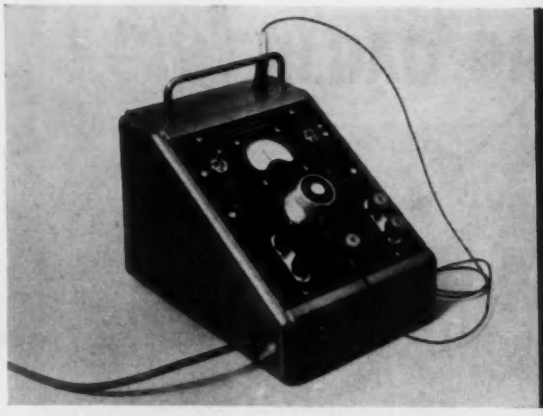

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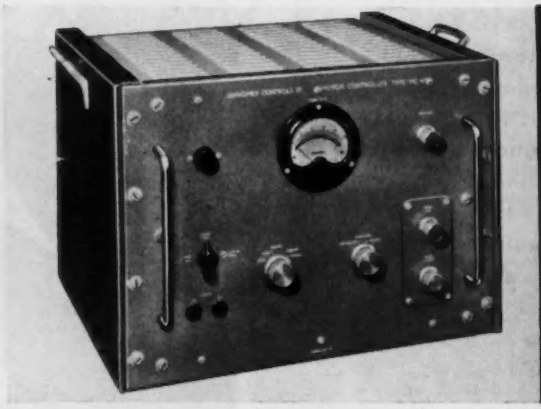

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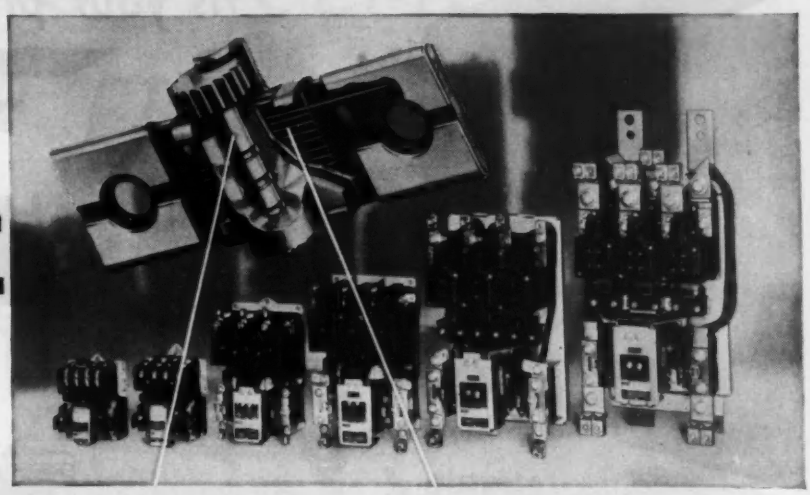

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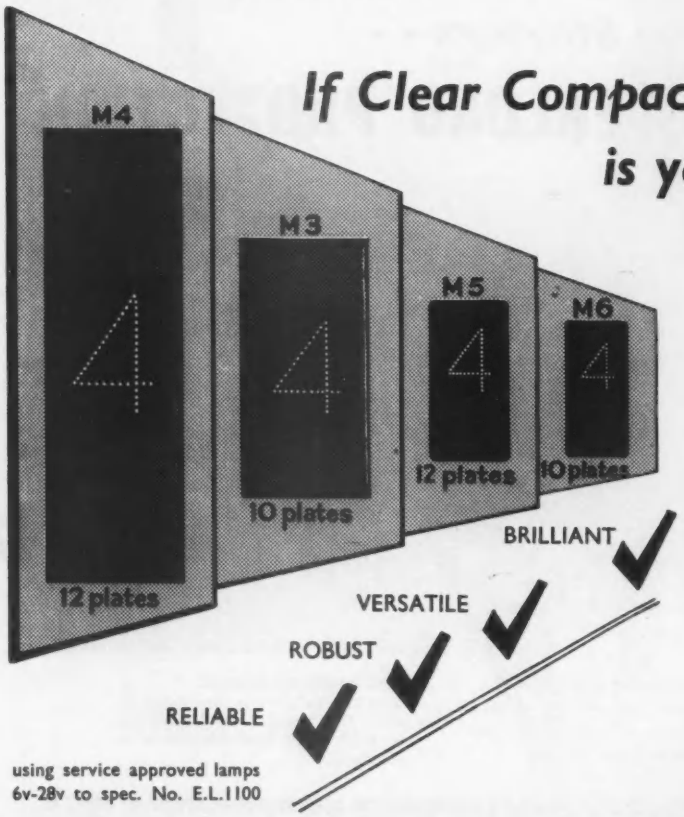

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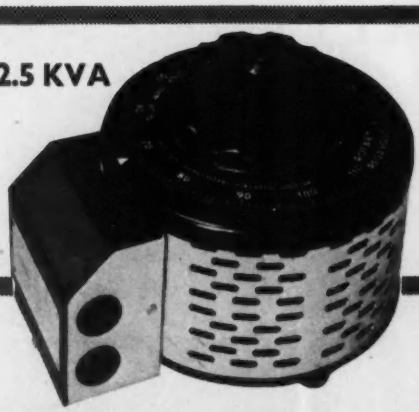

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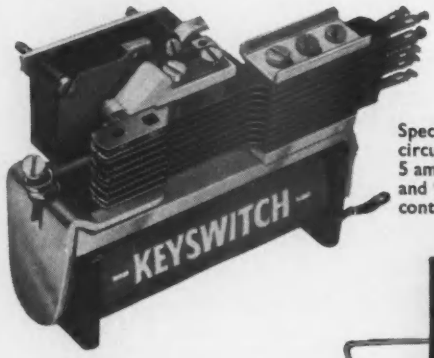

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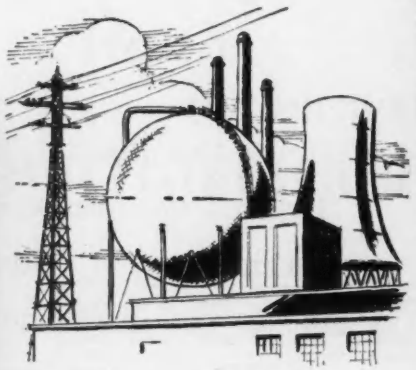

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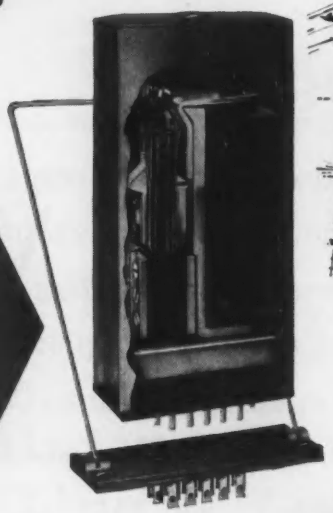

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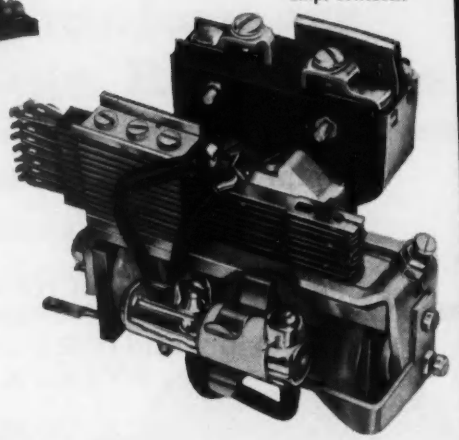

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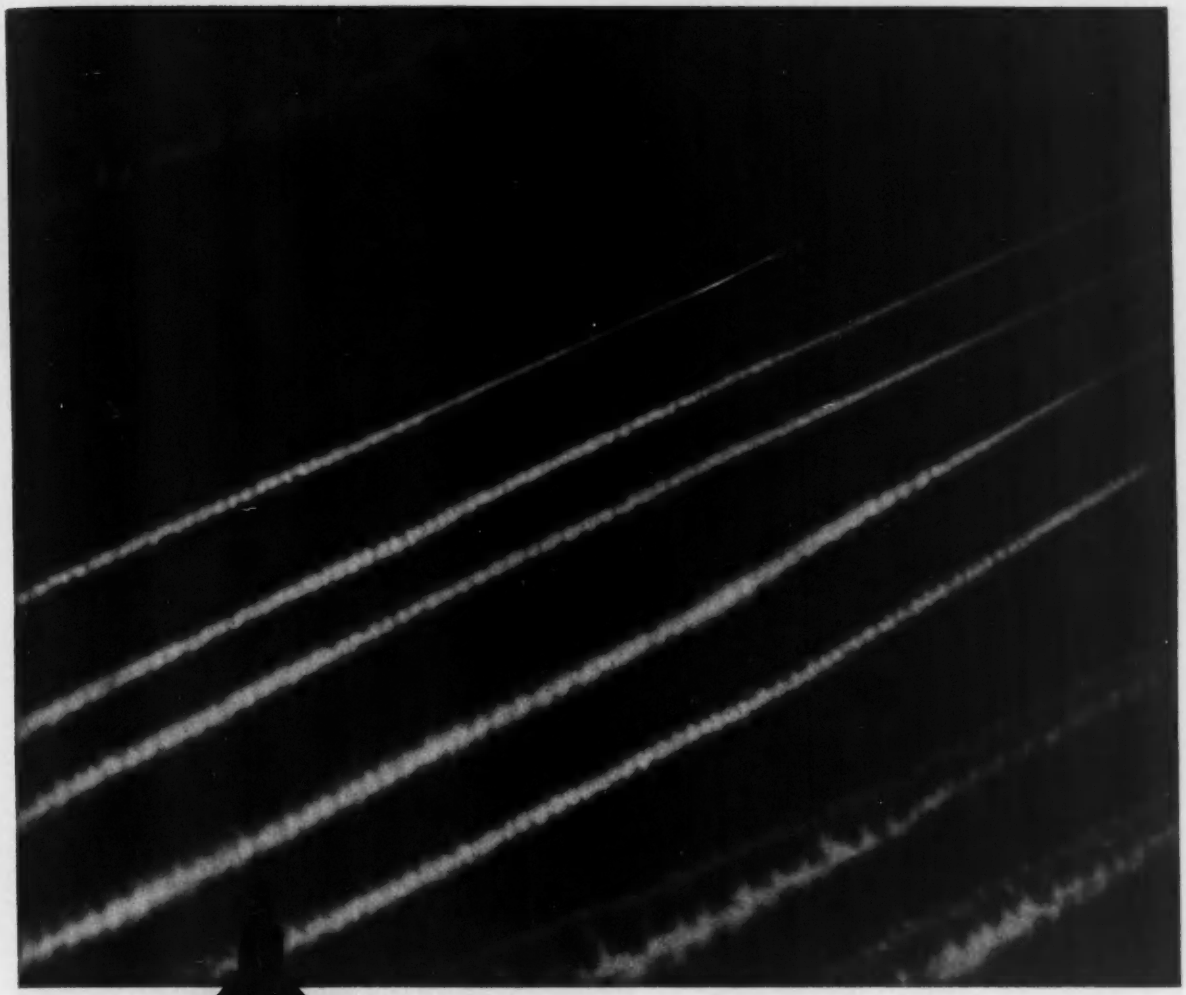

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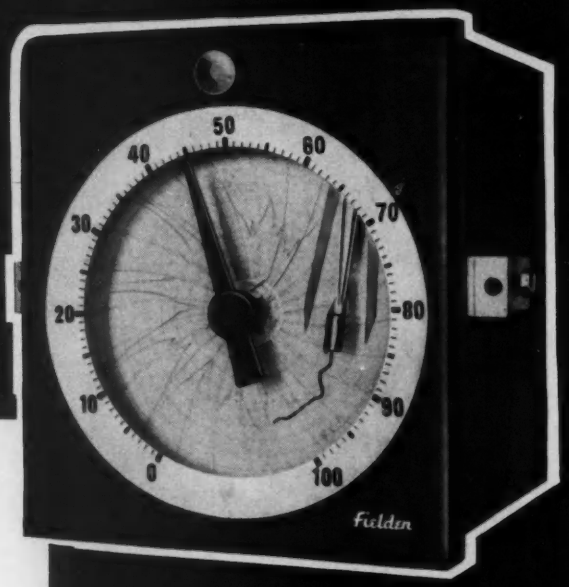

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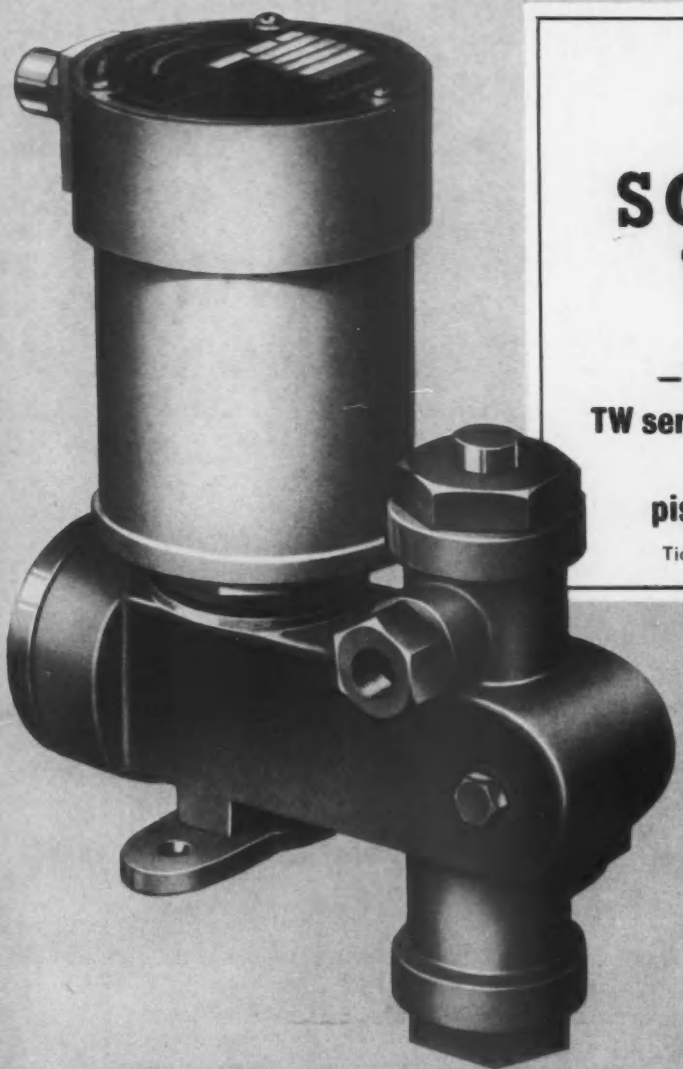

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—illustrated is one of the TW series high-performance valves for diaphragm and piston-operated apparatus

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THE WASHING STAGE IN SEMI-CONDUCTOR MANUFACTURE

Issued by *ELGA PRODUCTS LIMITED*

The analysis below represents intrinsic* water, considered essential for rinsing transistors and similar devices. There are three methods of producing this very high purity water. Whatever method is used, effluent quality must conform to the analysis.

* intrinsic: belonging naturally—inherent—essential

METHOD 1

Individual line stations—mixed bed column

Observations: Effluent is conductivity water approaching 10 megohm-cm, no regeneration *in situ*. Appears to be satisfactory for most applications.

Limitation: Rather uneconomical in hard water areas.

METHOD 2

Central plant with regeneration in situ, connected to end purification stations

Observations: Effluent quality is "intrinsic water" of the order of 16 megohm-cm+. This approach appears to be generally acceptable and is very economical.

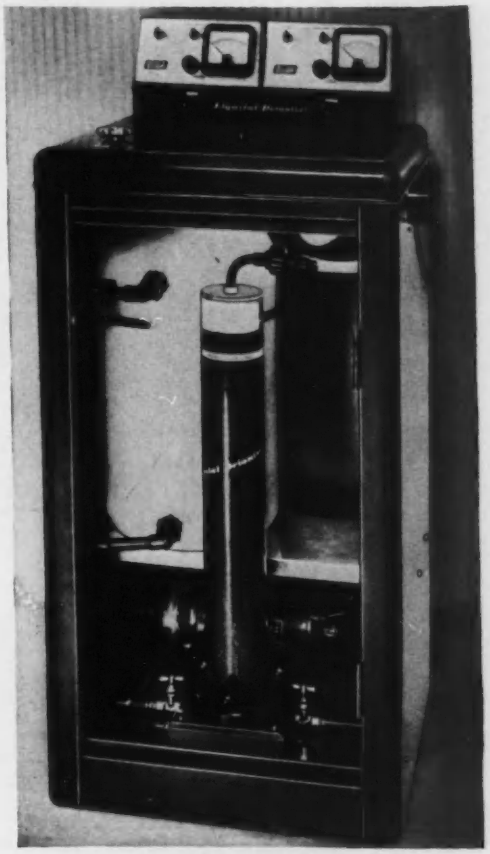
METHOD 3

Individual line stations—mixed bed recirculation

This method produces intrinsic water of the order of 16 megohm-cm+. No regeneration *in situ* or central plant required.

Observations: Acceptable effluent for all known applications, virtually no maintenance. Negligible effluent cost: £2. 10. 0. for 6 to 10 working days. An example of a mixed bed recirculator is shown. This model cost £187.

The Company specialises in the design and manufacture of deionisers for the provision of intrinsic water. Publication CTL 1 includes a paper "Intrinsic Water for Semi-conductor Washing". Please ask for a copy.



The Elgastat Robot B.106.

DEIONISED EFFLUENT ANALYSIS	RESULTS
Trace metals	*Not present*
Silica	*Below 0.1 p.p.m.*
Chloride	*Not present*
Sulphate	*Not present*
Ammonia	*No coloration with Nessler's reagent*
Carbon dioxide	*Not present*
pH value	*6.6-7*
Electrical resistance	*10 megohm-cm+*

If it's ion exchange ask ELGA first

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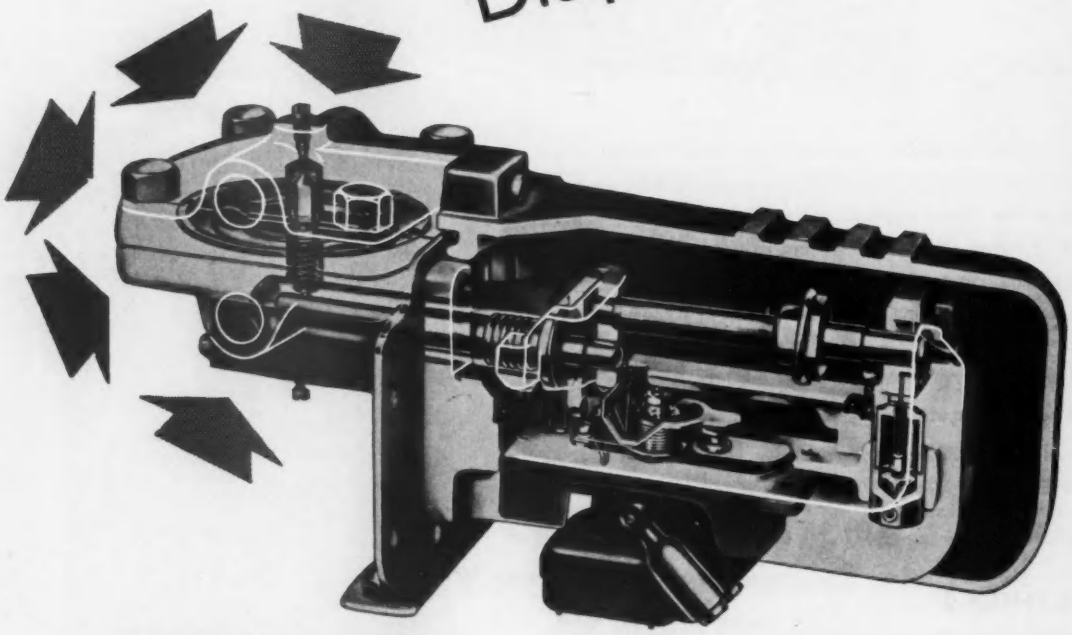
LANE END BUCKS Telephone: Lane End 396

New Diaphragm



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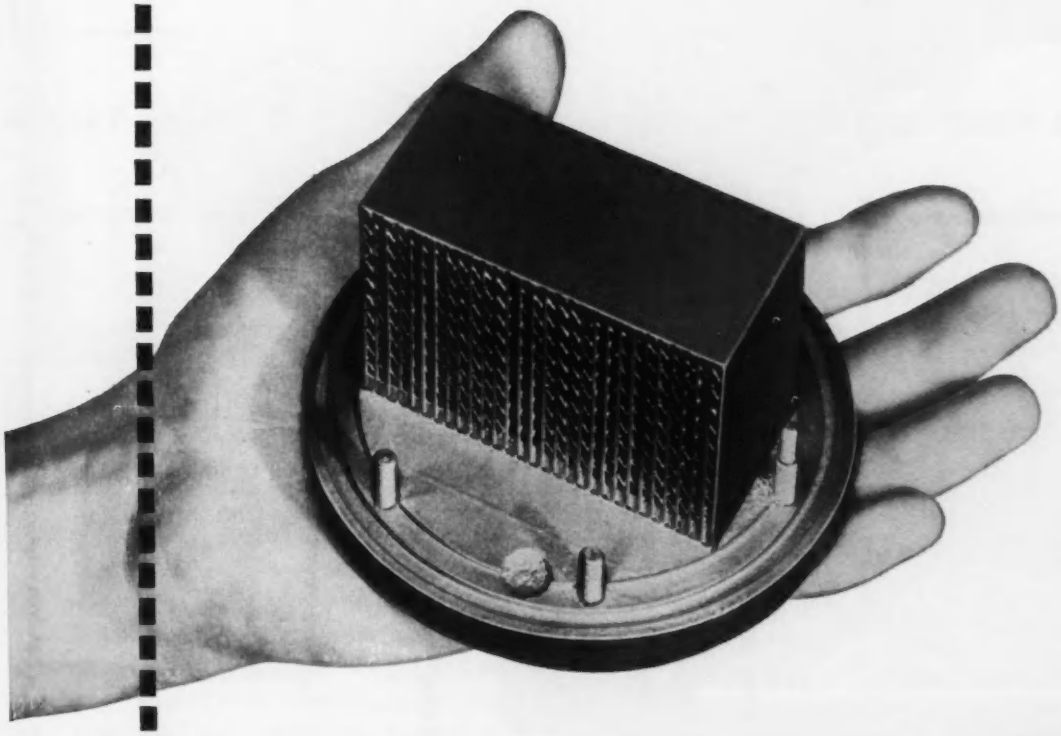
In a sense it's an optical illusion. A magnetron valve cooler made by Marston sits snug in the palm of the hand—but, thanks to the ingenious corrugations of the secondary surface heat-exchanger, it presents two-and-a-half square feet of surface area. This is just one instance of the compact coolness Marston offers the electronics industry. Marston heat-exchangers, whether air- or liquid-cooled, are designed specifically for preserving component life and efficiency and reducing the drift of transistor characteristics. Don't design round these problems: Marston can help you overcome them.



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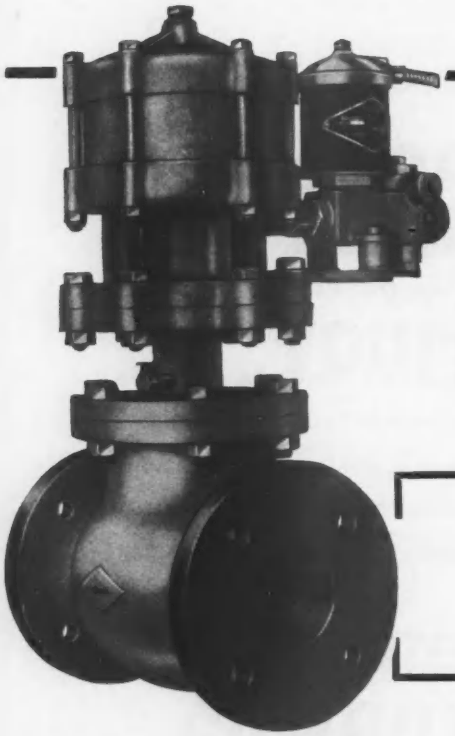

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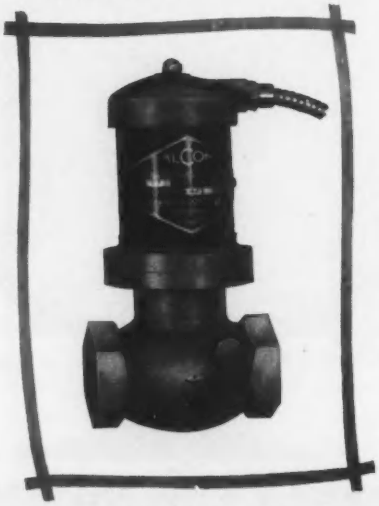

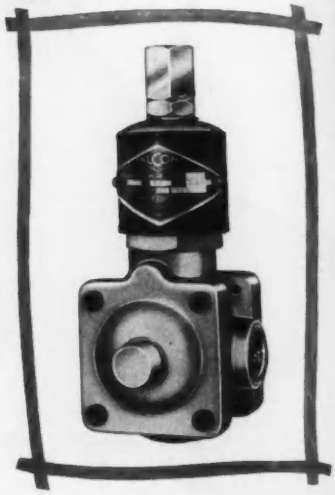

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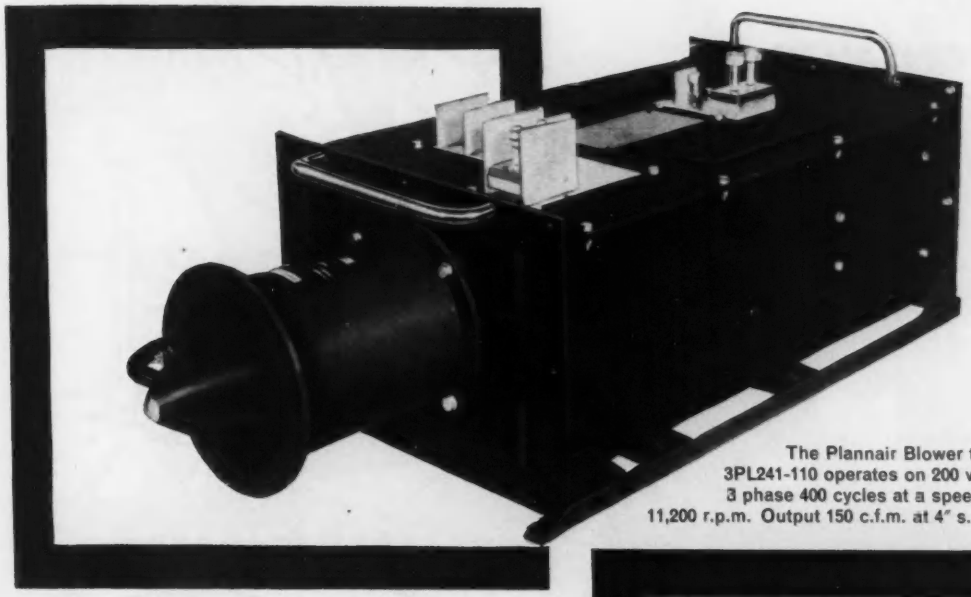
PLANNAIR keeps things temperate for Ferranti aboard the 'Vanguard'



The Plannair Blower type 3PL241-110 operates on 200 volts 3 phase 400 cycles at a speed of 11,200 r.p.m. Output 150 c.f.m. at 4" s.w.g.

This beautifully engineered transformer/rectifier unit by Ferranti is installed in Britain's newest airliner, the Vickers Vanguard. The unit is, in Ferranti's words, ' an assembly giving the minimum overall dimension and weight.'

In such compact equipments, cooling is a critical factor. It must be adequate and the cooling source must also be lightweight and efficient. Like Ferranti, most manufacturers of advanced electronics rely on Plannair blowers to solve temperature control problems.

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Whenever you are faced with the problems of getting enough air in the right place, take them to Plannair—that's what the rest of the industry does!

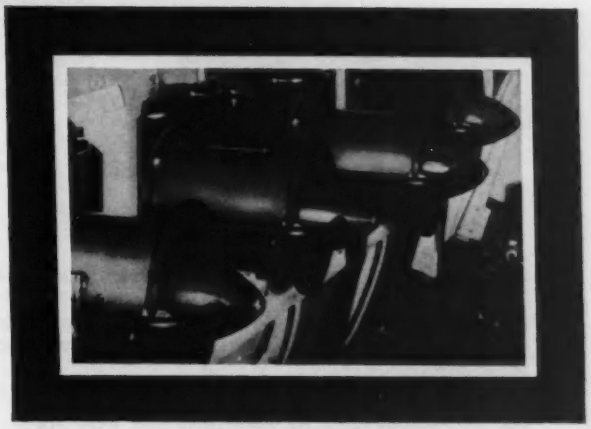

Illustration shows four single stage blower units type 3PL241-110 installed for transformer/rectifier cooling on the main d.c. power supply unit in the Vickers Vanguard.

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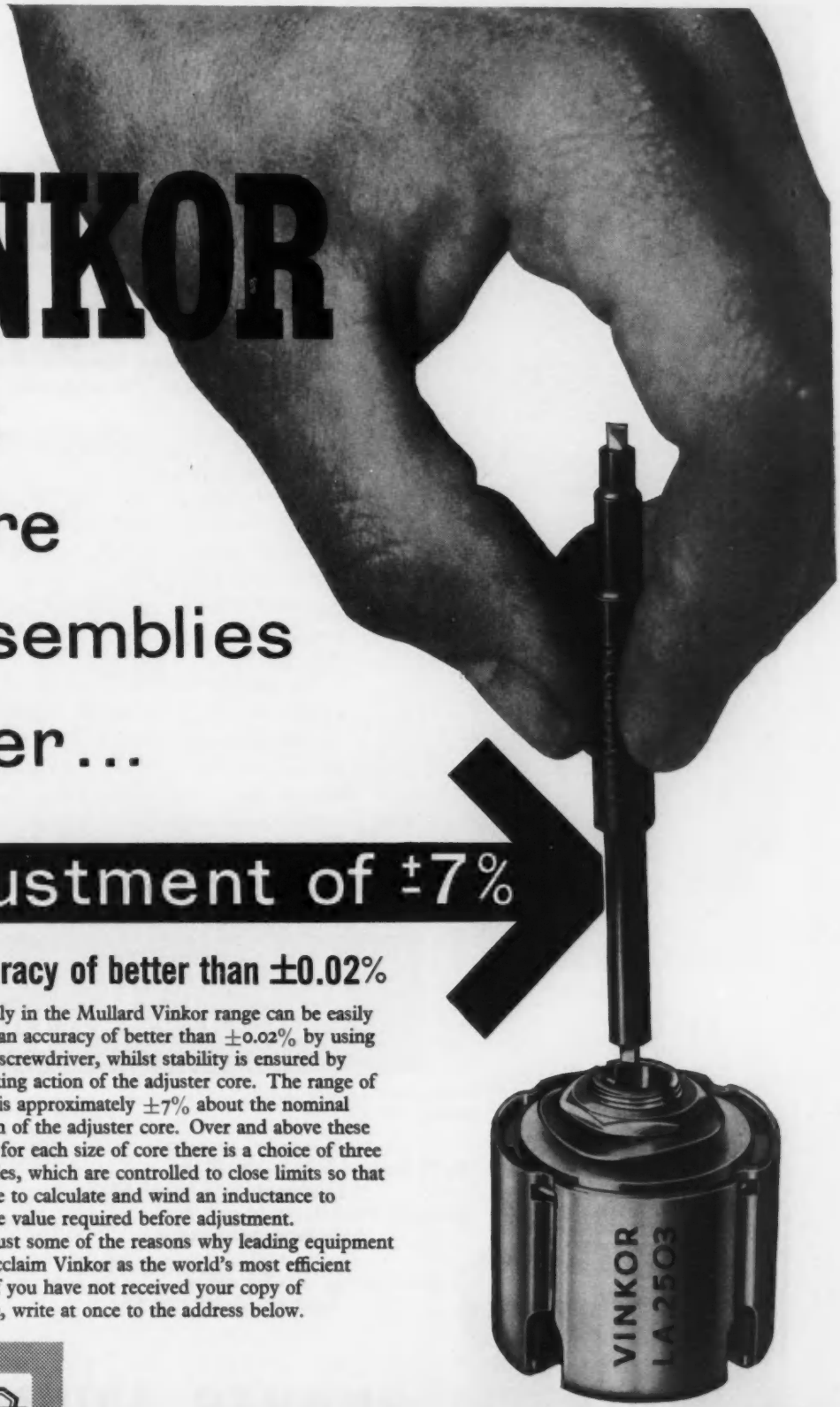

adjustment of ±7%

with an accuracy of better than ±0.02%

Any assembly in the Mullard Vinkor range can be easily adjusted to an accuracy of better than ±0.02% by using a trimming screwdriver, whilst stability is ensured by the self-locking action of the adjuster core. The range of adjustment is approximately ±7% about the nominal mid-position of the adjuster core. Over and above these advantages, for each size of core there is a choice of three permeabilities, which are controlled to close limits so that it is possible to calculate and wind an inductance to ±3% of the value required before adjustment.
These are just some of the reasons why leading equipment designers acclaim Vinkor as the world's most efficient pot core. If you have not received your copy of Vinkor data, write at once to the address below.

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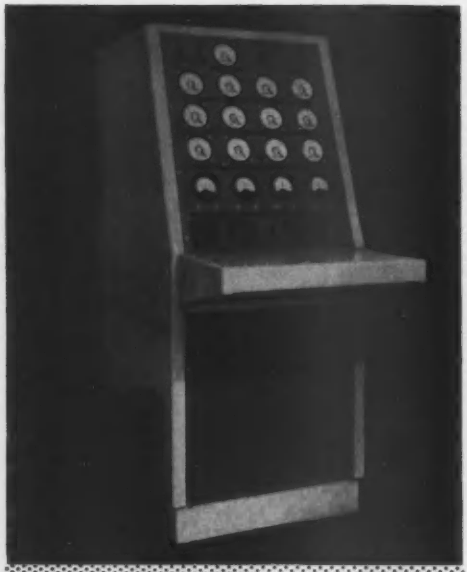
Mullard Ltd. Component Division, Mullard House, Torrington Place, W.C.1.

MC. 2868



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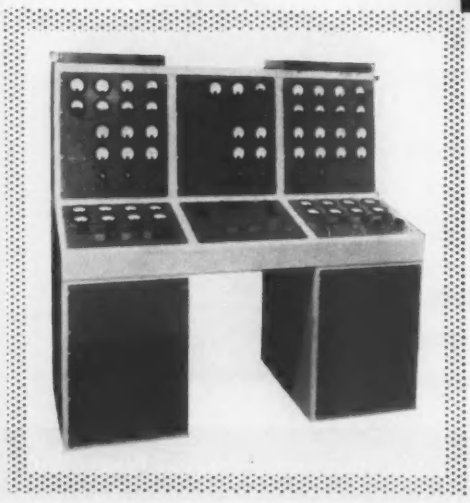

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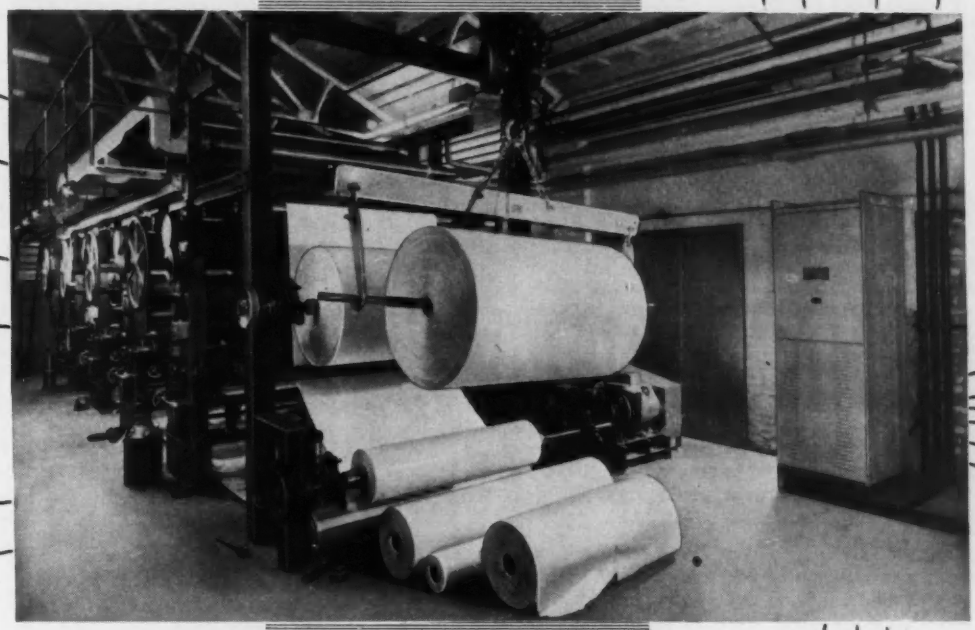

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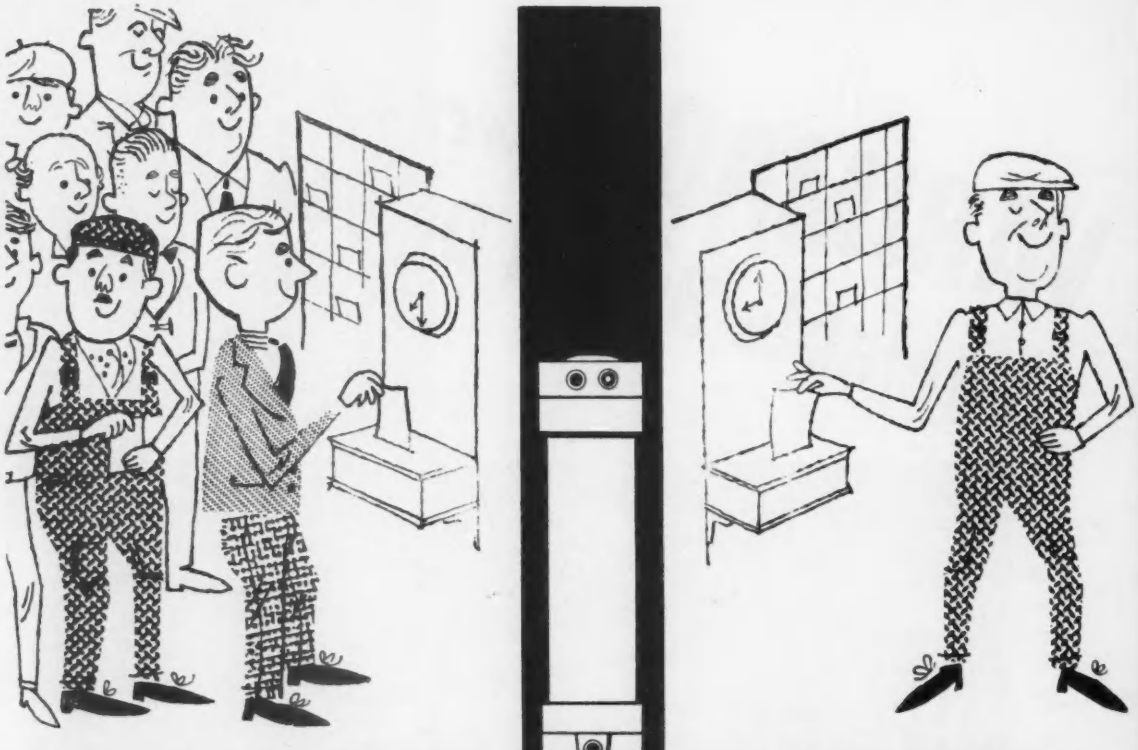

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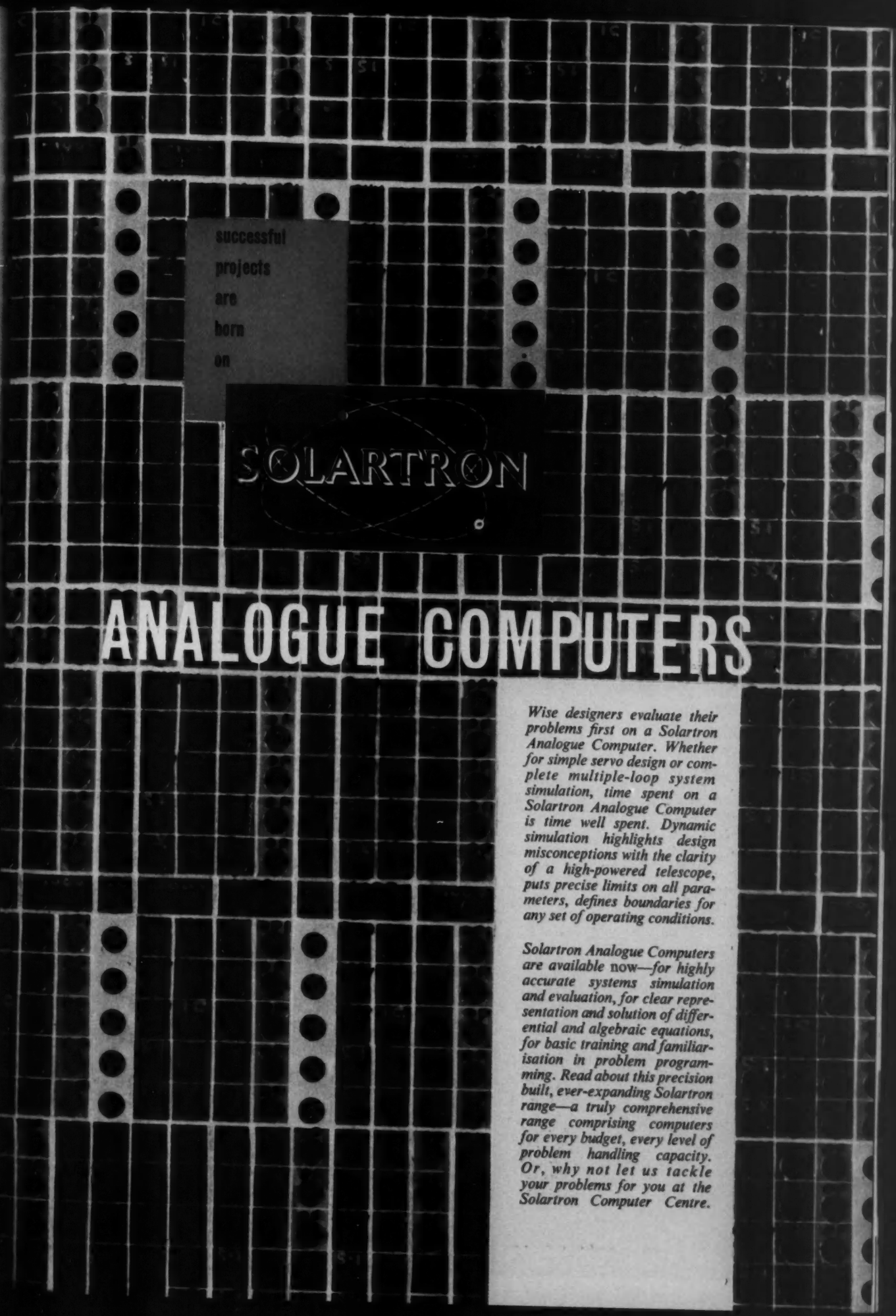
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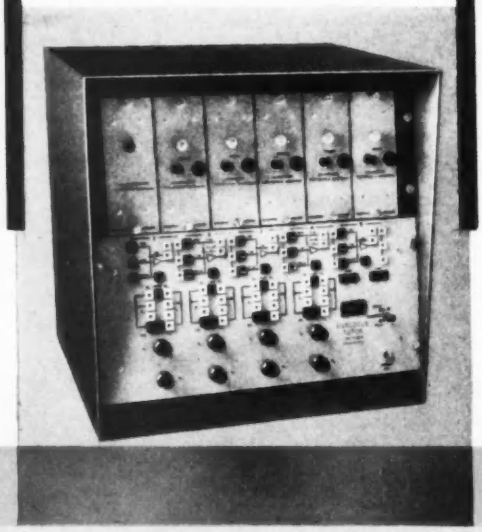
1 analogue tutor

Capable of demonstrating any form of second-order differential equation. Applications include representation of servos, simple electrical networks, motion of particles and like systems.



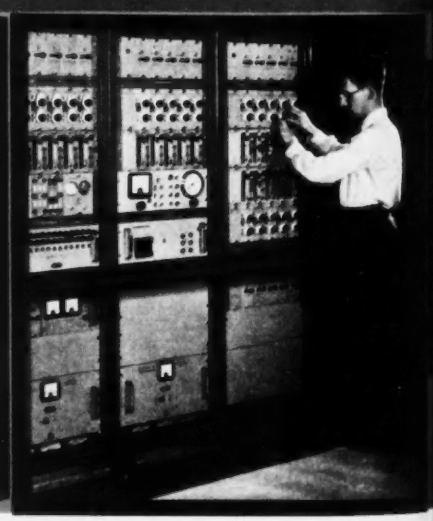
• A complete miniature computer for Student use

It is safer and cheaper to simulate mistakes than make them. Without having to build it, here is your projected system brought to your very desk-side or laboratory!

The Solartron SPACE '30' analogue computer (right) is unique in flexibility of application. With an operational capacity greater than many computers using 40 or more amplifiers, SPACE '30' has an additional problem-beating complement of non-linear units for direct analogue simulation of almost any dynamic system. Even when many complex system elements must be included as analytic or empirical non-linear operators, SPACE '30' will faithfully simulate according to the known information to produce a highly accurate prediction of dynamic performance.

All Solartron analogue computers are built using a highly flexible modular construction technique. Thus at any time, your Solartron machine need only be as complex as budget and work demand. Special machines, like the Auto-Control Simulator illustrated here, or the SPACE '30' series, can be expanded or multiplied at a moment's notice.

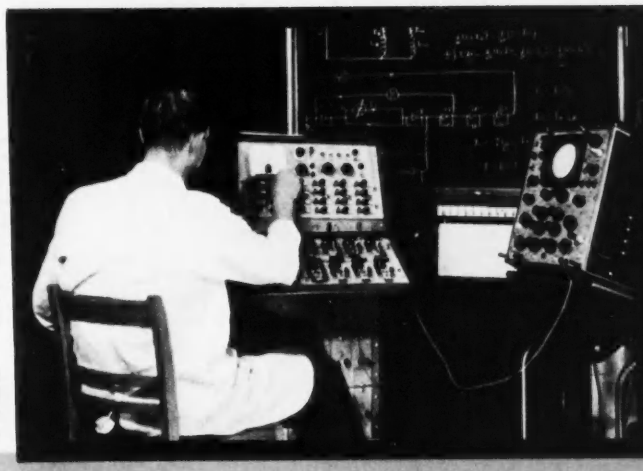
4



ANALOGUE COMPUTERS

The Analogue Computer is the foremost aid to training in feedback techniques and theoretical servo analysis, also for clearly representing and solving complex differential equations.
Because of its common basic approach to all dynamic problems, analogue computing practice is vital to broadening engineering appreciation. Parallels between widely different systems are drawn with sudden lucidity — between hydraulic controls and national economics for example, or between a nuclear reactor and a controlled biological culture. Every problem solved on an analogue computer brings a wealth of dynamic knowledge, relevant to wide areas of subsequent work.

MINISPACE * Provides high accuracy at low cost * Ideal for servo simulation and basic reactor studies for students. * Eminently suitable for sub-programming larger machines.

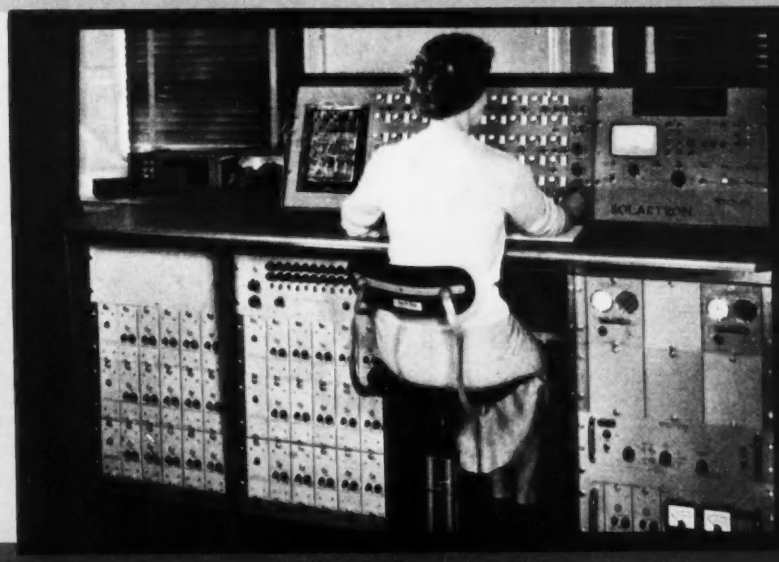


2 minispace

★ Solves linear or non-linear problems: up to 5th-order differential equations.

★ Easily expanded to greater problem capacity.

For handling even bigger problems, your SPACE '30' installation can be multiplied to give 60 or 90-amplifier capacity—or, in the preferred case, you can choose a SPACE '60' or SPACE '90' machine, each fully integrated for centralised programming and control.



3 space '30'

★ 30 amplifiers in new, optimised design configuration.

★ Full complement of non-linear computing elements.

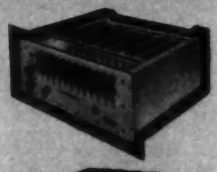
★ The first choice for complex dynamic simulation of any kind.

★ Easy to use — easily expanded.

FOR INDEPENDENT USE

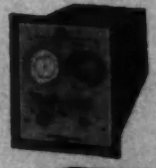
These three Solartron Analogue Computing Units are typical of many which exist in their own right as precision instruments and which are immediately available for use independently, or in existing analogue computing installations.

Full technical literature is available on request.



- 12-Segment, high accuracy function generation. ± 100 V output, 0.5% long-term stability.
- Rapid, accurate break-point setting in Cartesian co-ordinates, by digital volt-meter.

5 diode function generator TR 829



- Fastest response available: accurate f.s.d. up to 10 c/s.
- Six-section pot, driven directly from servo.
- Self-contained with transistor feedback amplifier and power supply.
- Multiplies up to five variables by one other or generates up to sixth power.

6 servo multiplier TJ 725

- 0.005% limit on deviation between positive and negative 100V supplies. NPL certificate on request.
- Better than 0.1% long term accuracy and 4,000 to 1 stability ratio.
- Incorporates Weston cell as reference source.

7 precision reference power supply AS 756·2

THE SOLARTRON Computer Centre at the Dorking Research and Development Laboratories of the Solartron Group offers comprehensive facilities for dynamic problem evaluation, programming and detailed solution on SPACE '30' Analogue Computers. Skilled personnel will, if you require, translate your problems into computer language and carry out all the operational procedures.

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THE SOLARTRON ELECTRONIC GROUP LIMITED (Computer Division)
Victoria Road, Farnborough, Hampshire. Telephone: Farnborough (Hants) 3000

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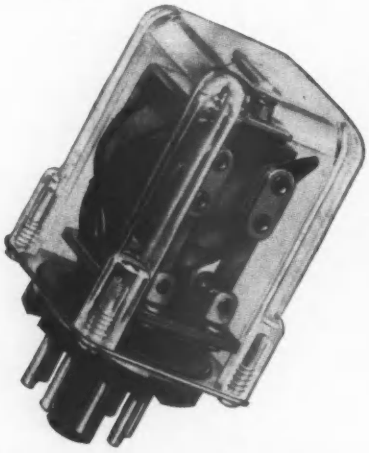
New...THORN PLUG-IN RELAYS

Thorn Pygmy Power Relay



New interchangable relay designed for use in remotely controlled automation units. Has double pole changeover contacts.

Dust proof—transparent plastic cover.

Plugs into any standard International octal valve base.

Weight Only 4½ ozs . . . projection only 2" above base.

Mechanical life over 10,000,000 operations.

Switching current: 5 amps maximum at 250 volts A.C.
Maximum surge current: 10 amps.
Operate time: 8 milliseconds approx.
Release time: 6 milliseconds approx.
Overall dimensions: 1⅝" square by 2$\frac{9}{32}$"
Coil voltage: 240 volts standard; also available for 6, 12, 24, 48, 60, 110 volts

Thorn T9 Micro-Switch Relay

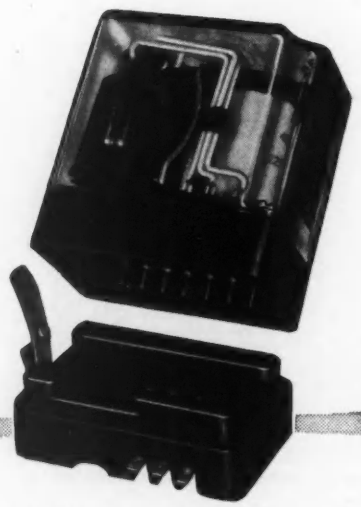
A plug-in relay, particulary suitable for switching P.A. equipment, the snap action contacts minimising interference with pick-up leads.

Operating coil wound for any specified voltage up to 240 volts A.C. or 150 volts D.C. May be tropicalised.

Up to three micro-switch pattern contacts mounted on standard coil frame.

Versions available with up to 11 solder tags or 10 screw terminals.

Contacts:	3 changeover.
Mechanical Life:	Over 10,000,000 operations.
C/O Time:	C.O. period less than 2 milliseconds.
Max. Switch:	10 amps/240 volts A.C. non inductive load.
Capacity:	0.2 amps/240 volts D.C. „ „ „ 0.5 amps/110 volts D.C. „ „ „ 1.0 amps/50 volts D.C. „ „ „ 5 amps/24 volts D.C. „ „ „
Max. Operate Speed:	20 cycles/sec.
Switching:	Up to 0.1 amp. approx. 20 cycles/sec.
Frequency:	„ „ 1 „ „ 5 „ „ „ „ 5 „ „ 1 „ „ „ „ 10 „ „ 0.1 „ „ (referred to A.C. non-inductive load).



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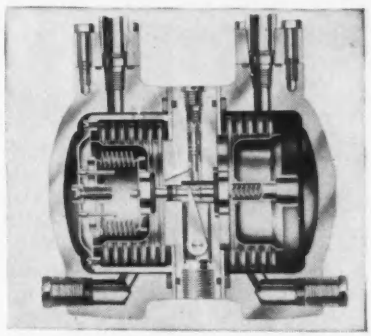
Thorn Electrical Industries Limited, Great Cambridge Road, Enfield, Middlesex. Telephone: ENField 5353

New Honeywell Bellows Meter

unequalled for accuracy, stability, versatility in flow metering



The new Honeywell Bellows Flow Meter gives the better performance demanded by its potential users. It's the most advanced meter body available today, with important advantages never before found in flow meters.
Some of its outstanding features:

Sensitive and accurate — Sensitive to within 0·05% of full scale . . . calibrated accuracy ± 0·5% of full scale.

Leakproof — Between liquid fill and process fluid.

Automatically stabilised — Changes in meter body temperature or static pressure have no effect on output shaft position. The Honeywell Bellows Meter operates efficiently in surrounding temperatures of between minus 40°F and plus 250°F.

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Fast, effective damping adjustment — New type pulsation check with rectangular orifice enables essentially linear damping adjustment . . . and you can adjust from outside the meter body during operation.

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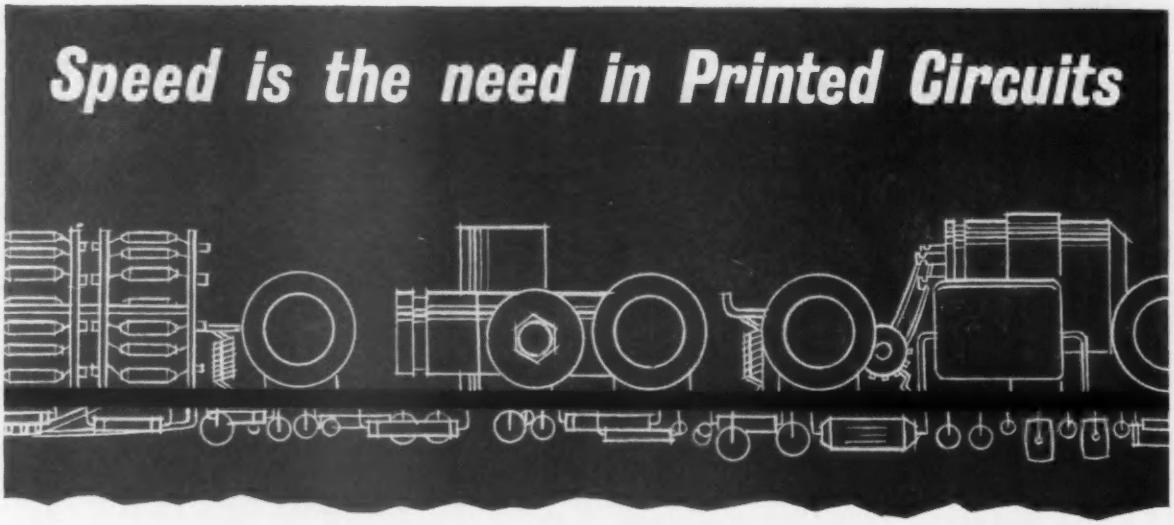
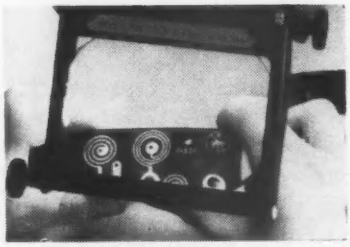
Speed is the need in Printed Circuits

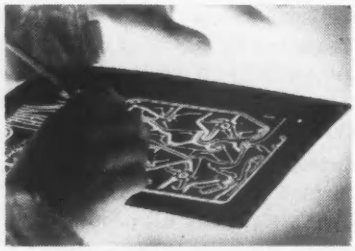


BRIBOND print circuits faster



The Printed Circuit is rapidly becoming established assembly practice in every field of electro-mechanics. Meeting this increasing demand takes specialist production such as only Bribond offers. Bribond manufacture circuits complete from design to finished board, and every stage is organised on modern line production methods providing outputs of any quantity. And each individual circuit is subjected to three critical inspections. This is increased when the copper is plated with either rhodium, silver, or gold.

BRIBOND make prototypes quicker



The prototype department is at the service of all Bribond customers. It can produce within 48 hours or less, the initial circuit from which future production can be planned. All that is needed is a clean circuit image from which reproduction can be made. Where desired, and time permits, the whole of this work can be carried out in our drawing office. Bribond recognise that quick prototypes—whether for complete units or small sub-assemblies—are essential in these highly competitive days when anything that shortens the time-lag between drawing board and production can mean a big reduction in marketing costs.

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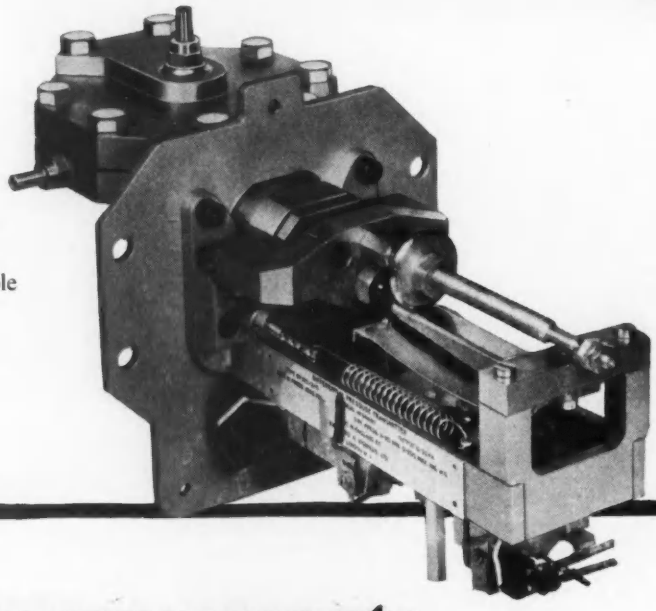

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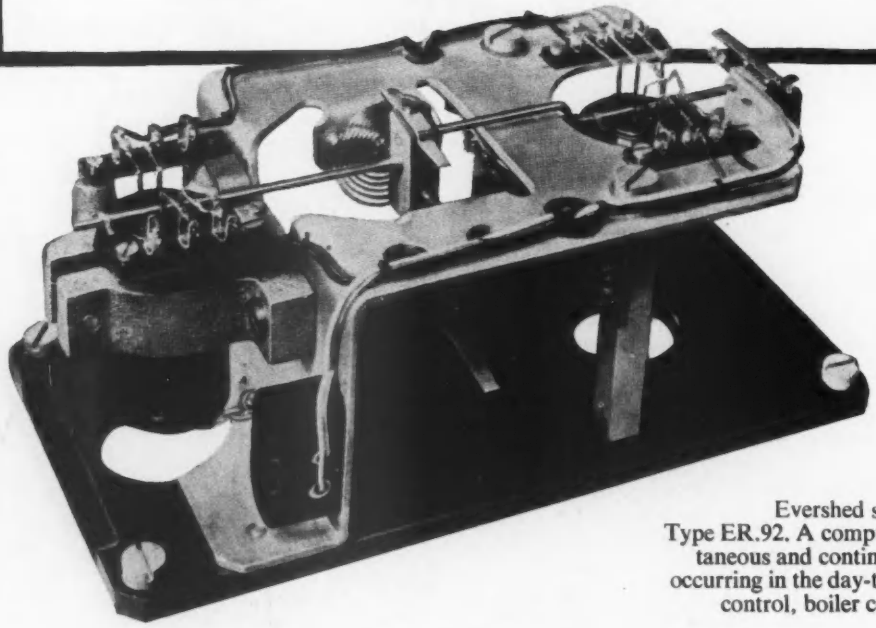

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TYPE 2000 with on/off control
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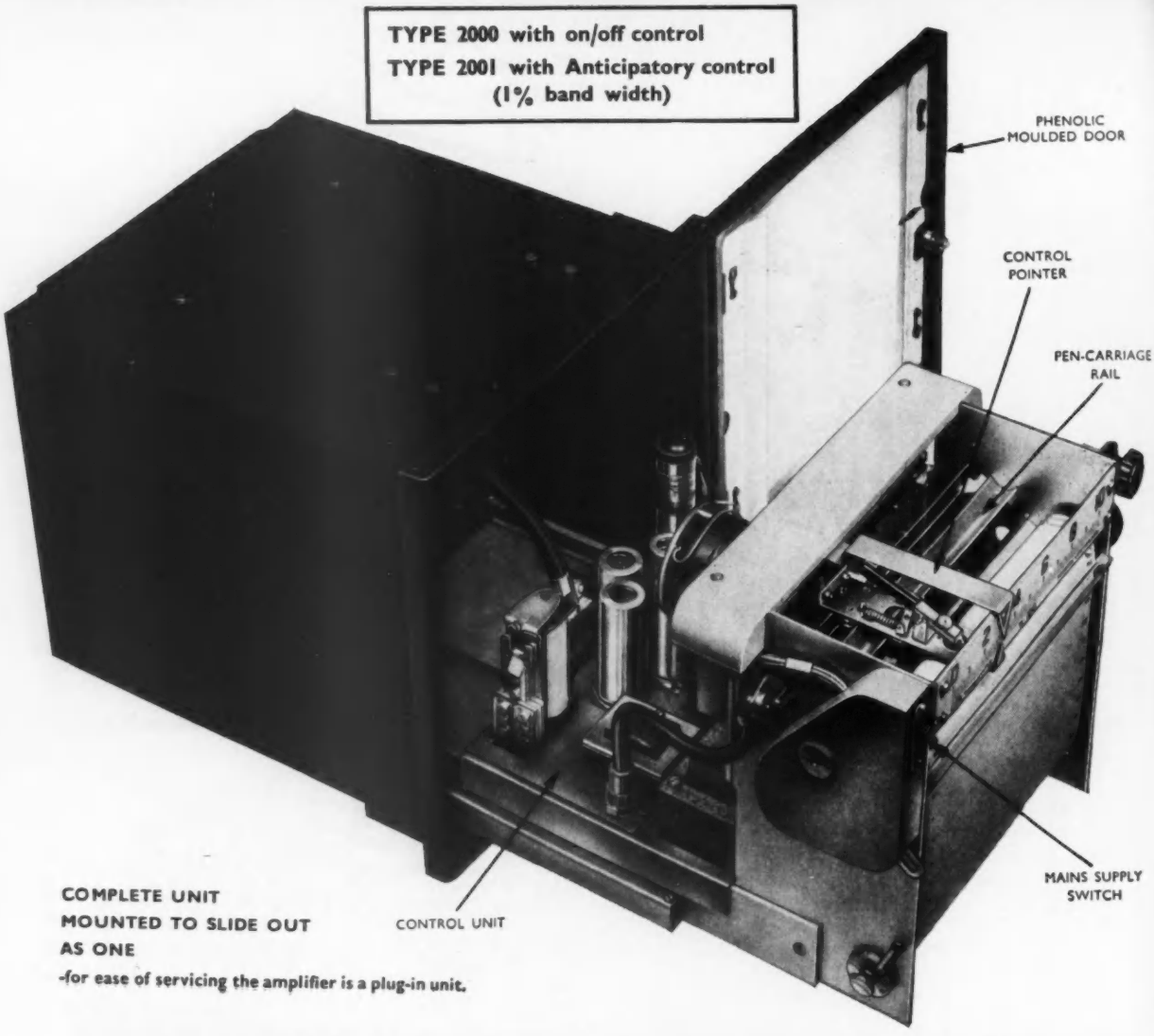

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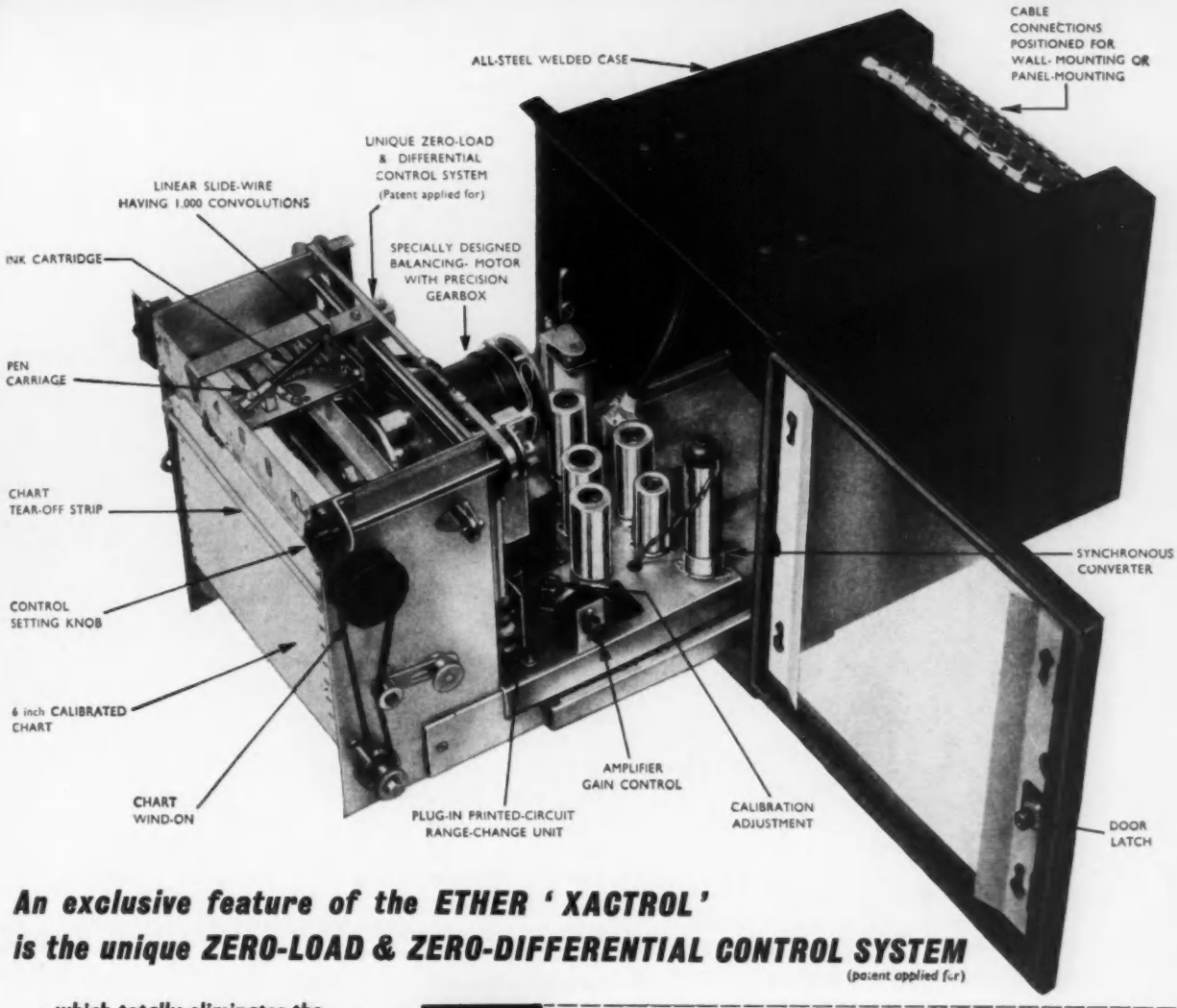

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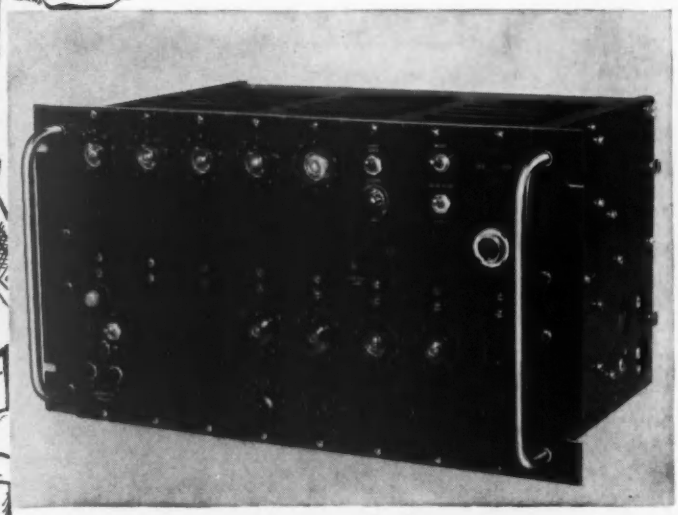

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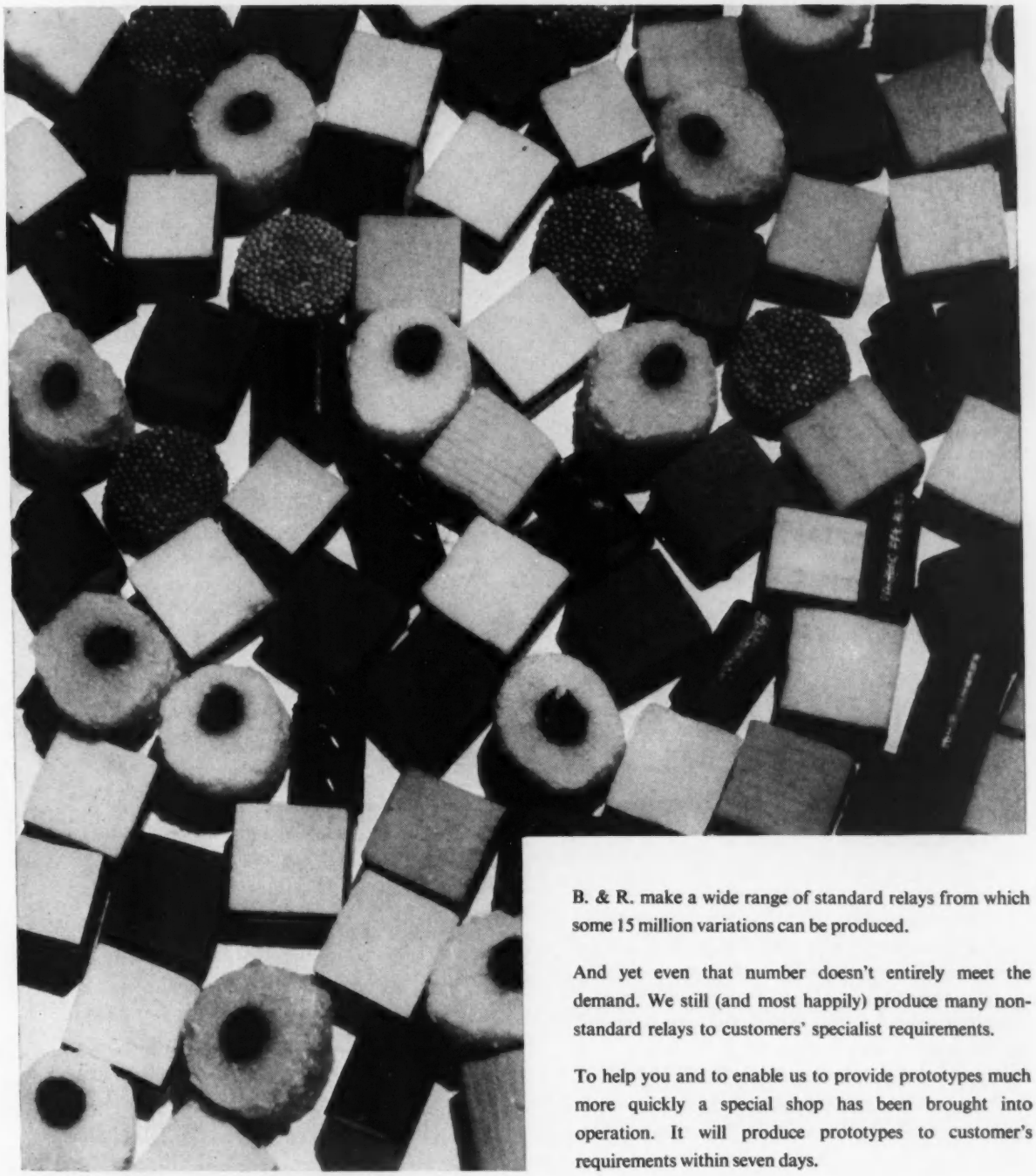

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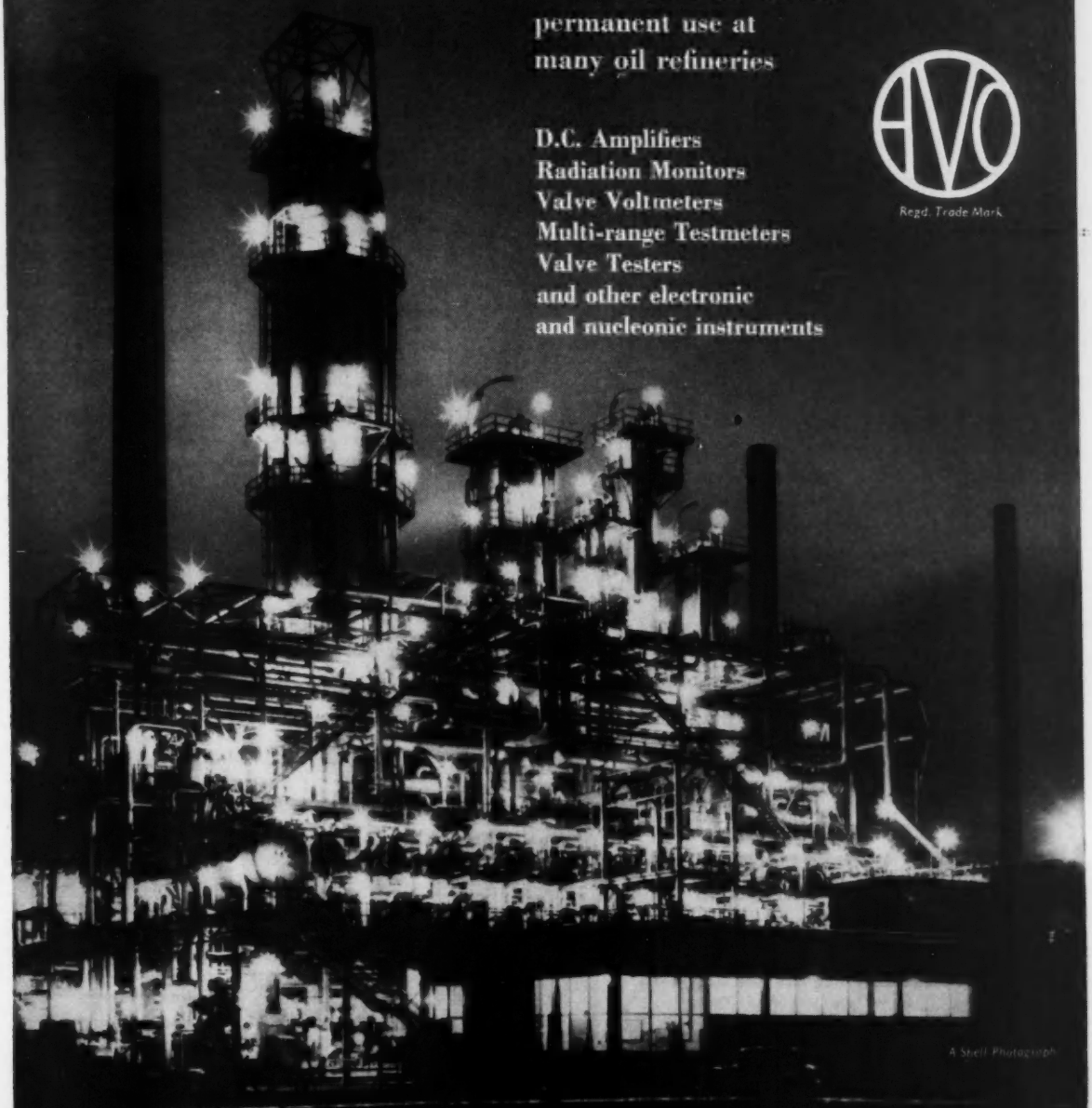

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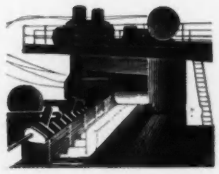
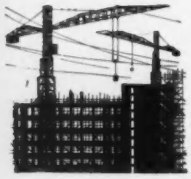
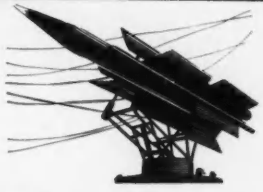
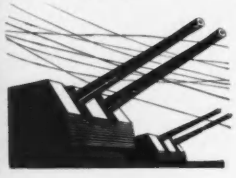




Design of heavy crane control gear

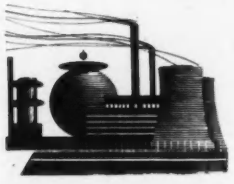
Missile servo analysis





Gun control problems

Reactor control mechanisms



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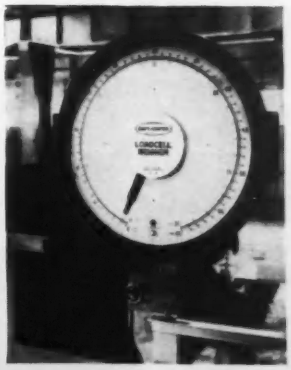

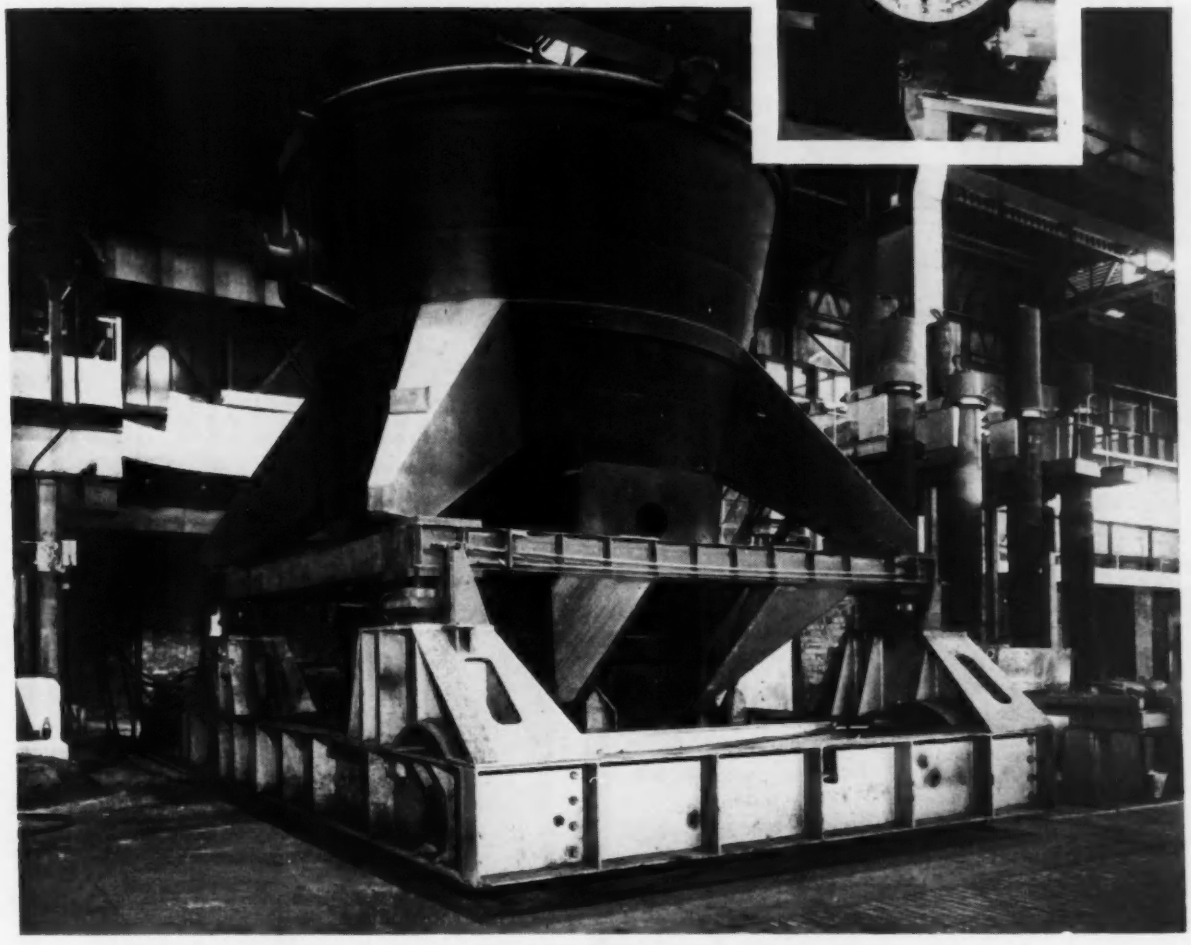

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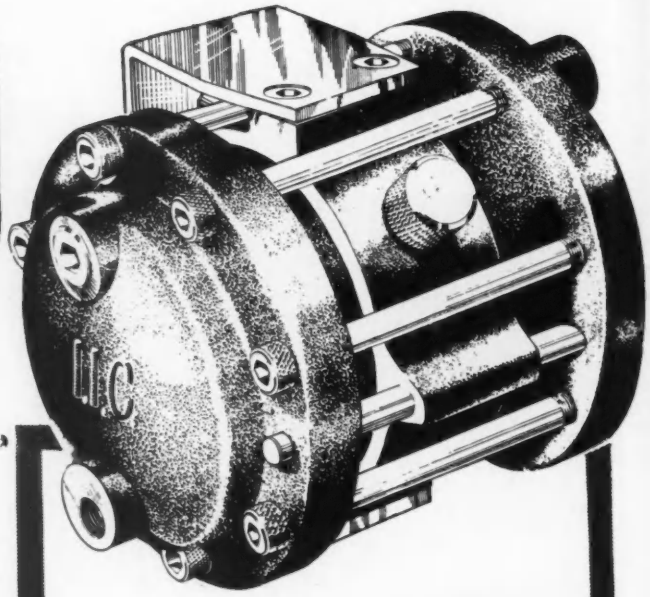
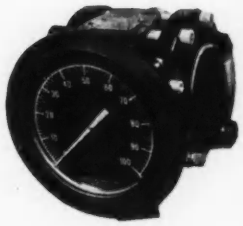
DAVY AND UNITED INSTRUMENTS LIMITED, DARNALL WORKS, SHEFFIELD 9

Dry Type Flowmeter

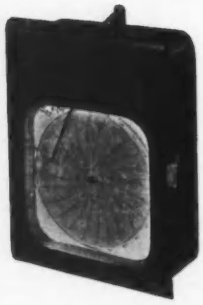


Elliott Brothers (London) Ltd. now manufacture the I.I.C. differential pressure flowmeter and its associated range of instruments in England. This unit in conjunction with Bristol's and Elliott recording, controlling and transmitting equipment is the last word in flow control: this is proved by the hundreds in operation in the Chemical, Oil, Rubber, Plastics and Paper Pulp industries.

Above: The I.I.C. differential pressure flowmeter



Above: Model 800-6 differential pressure indicator



Above: Bristol's Series 500 recorder (supplied with or without spring driven or electric integrator)

Right: Model 700 MT pneumatic differential pressure transmitter

FEATURES

- ★ Complete over-range protection
- ★ Sustained High accuracy
- ★ Seamless bellows Heliarc Welded
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- ★ One bellows unit for all pressure ratings

Further information on the I.I.C. flowmeter is freely available from:

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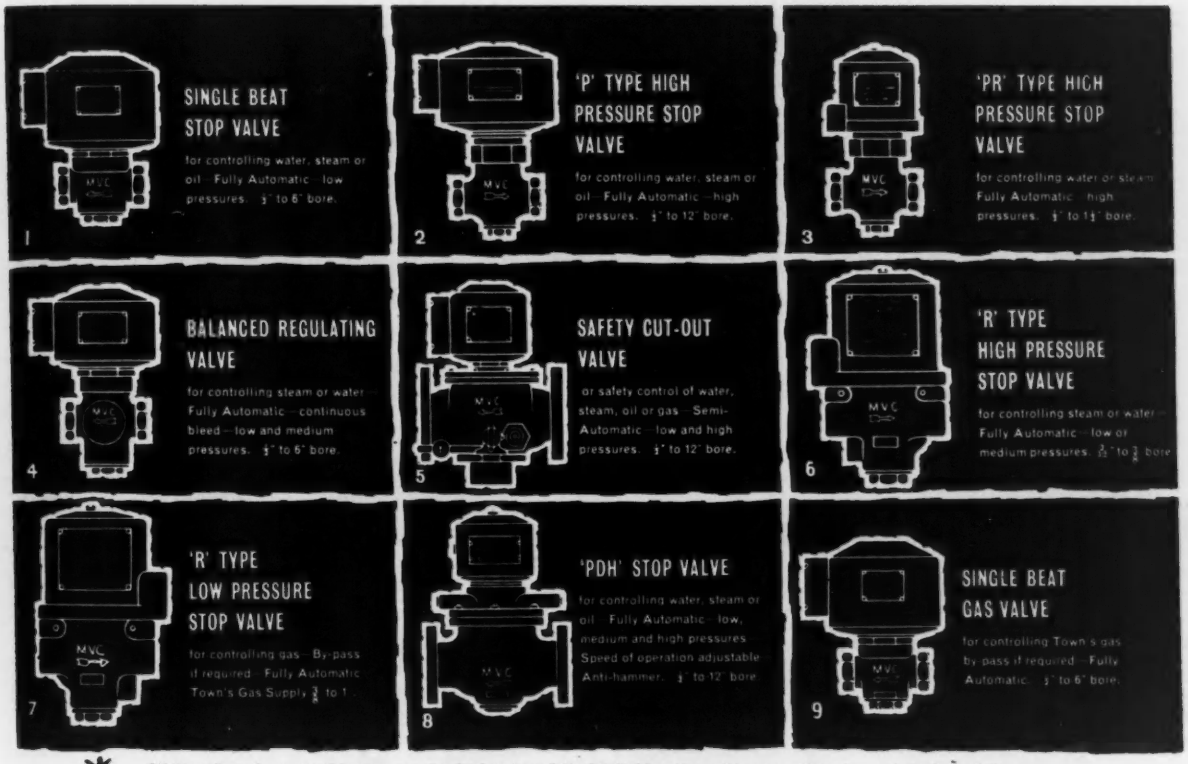
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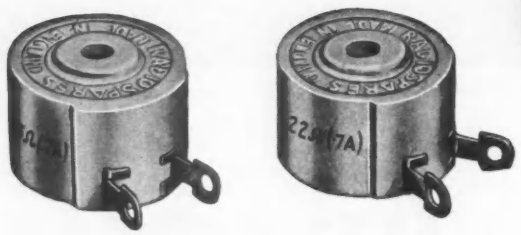

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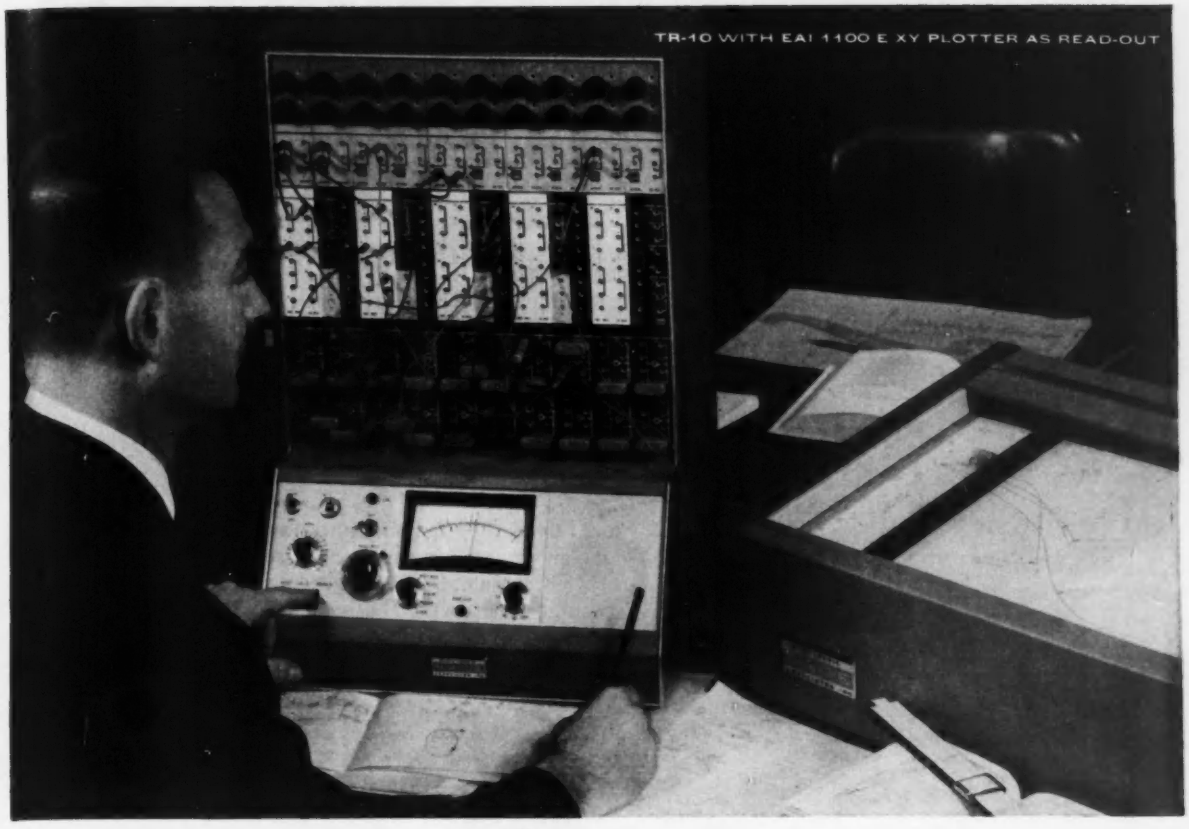

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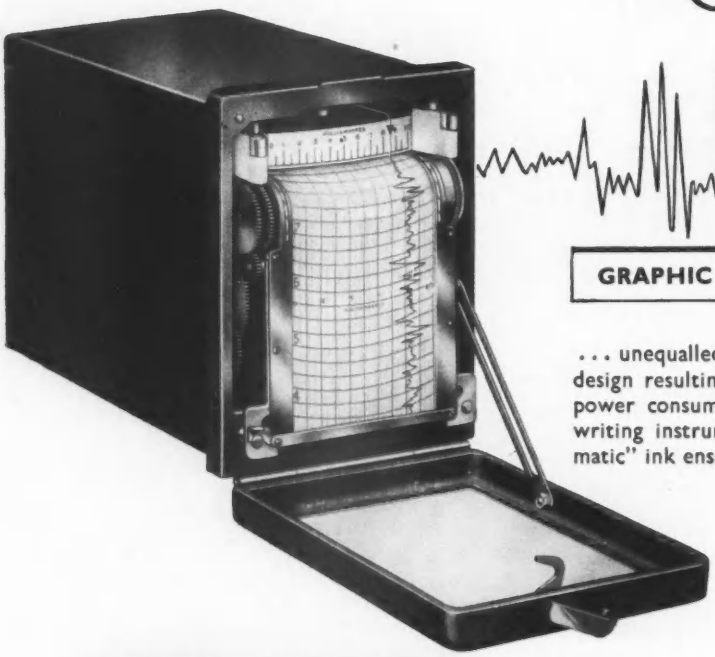

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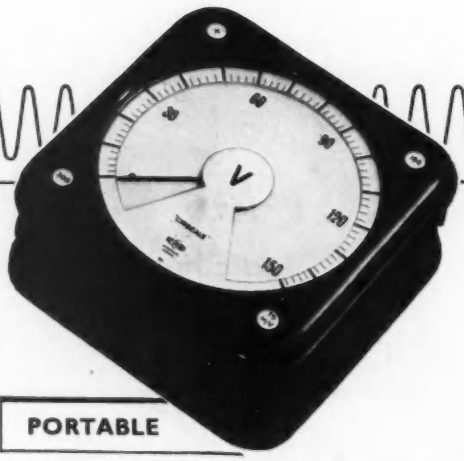

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40mμsec. 8V peak in 75Ω, positive going.

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Width: Variable from 0·09μsec to 105msec ±5%.

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25V max in	600Ω	rise time <40mμsec
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Polarity: Positive or negative going.

Accuracy: ±2%.

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Conclusion of pre-pulse to advent of main pulse, delay variable from 0·09μsec to 105msec. Accuracy ±5%.

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D.C. coupled negative going sawtooth same width and delay as main pulse.
15V peak max.

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Obtained from short circuited pure line.
One positive and one negative going pulse coincident with main pulse.
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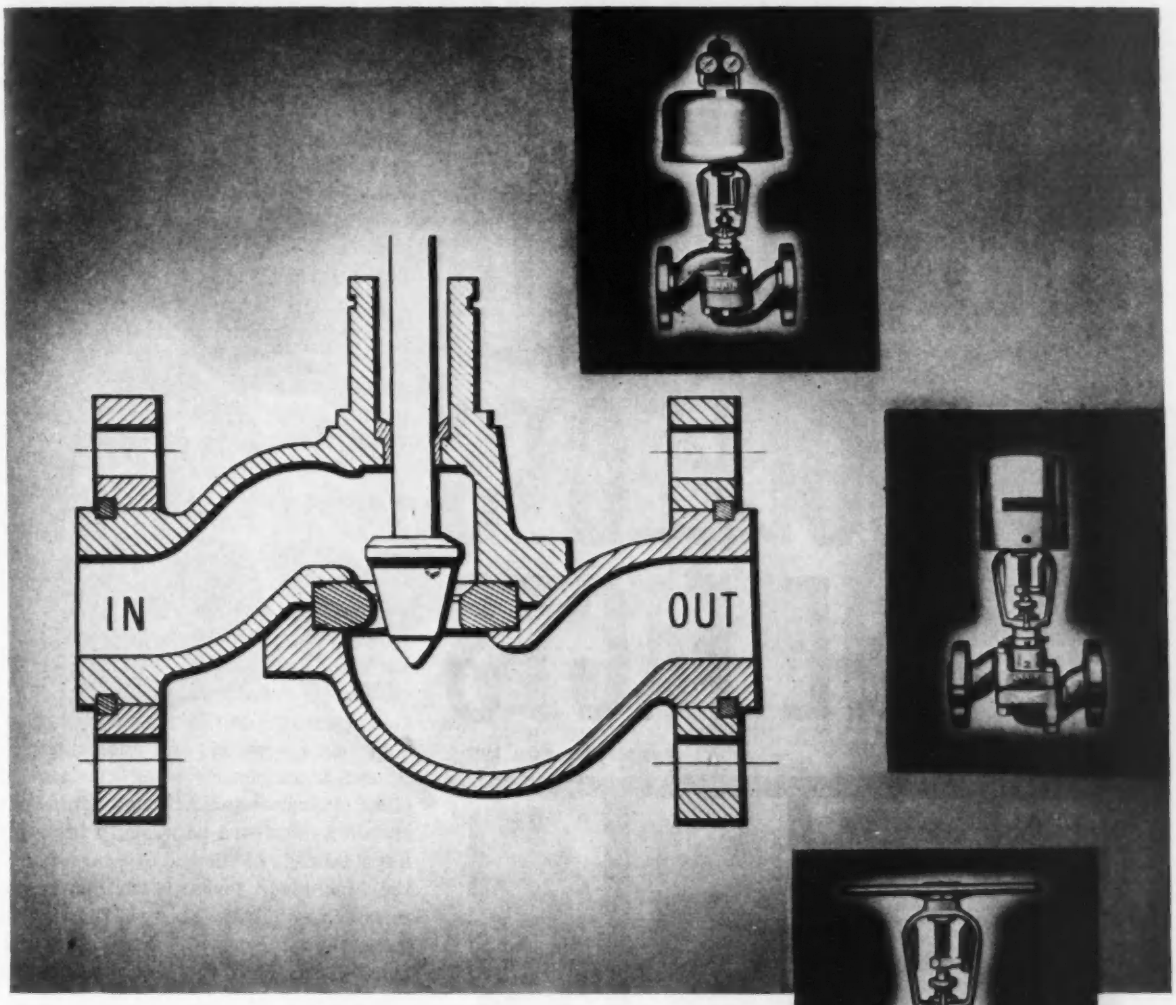

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COLLECTS THE FACTS

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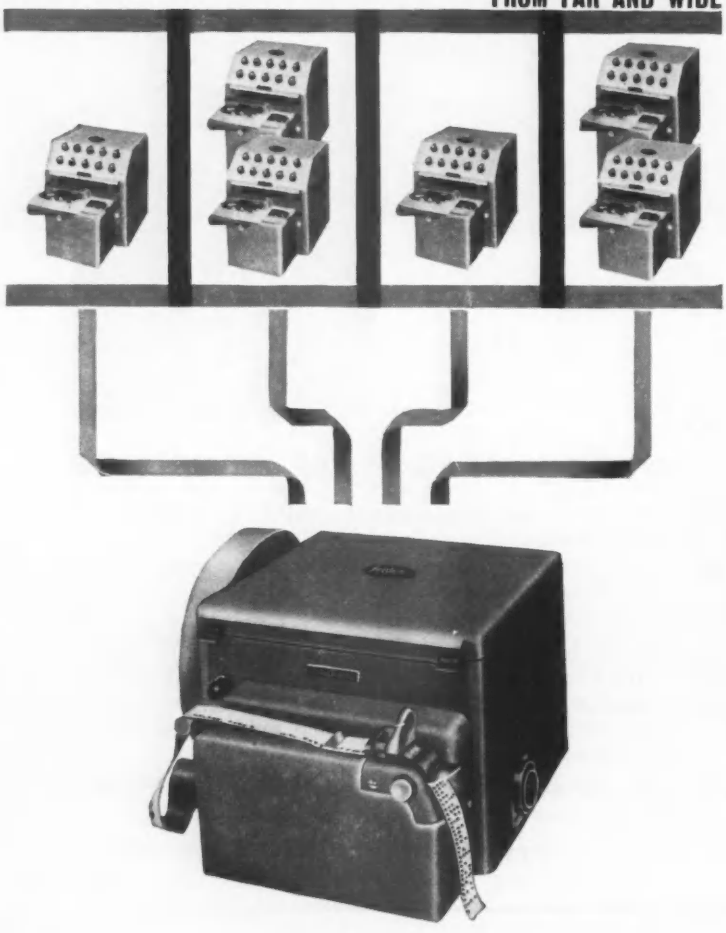

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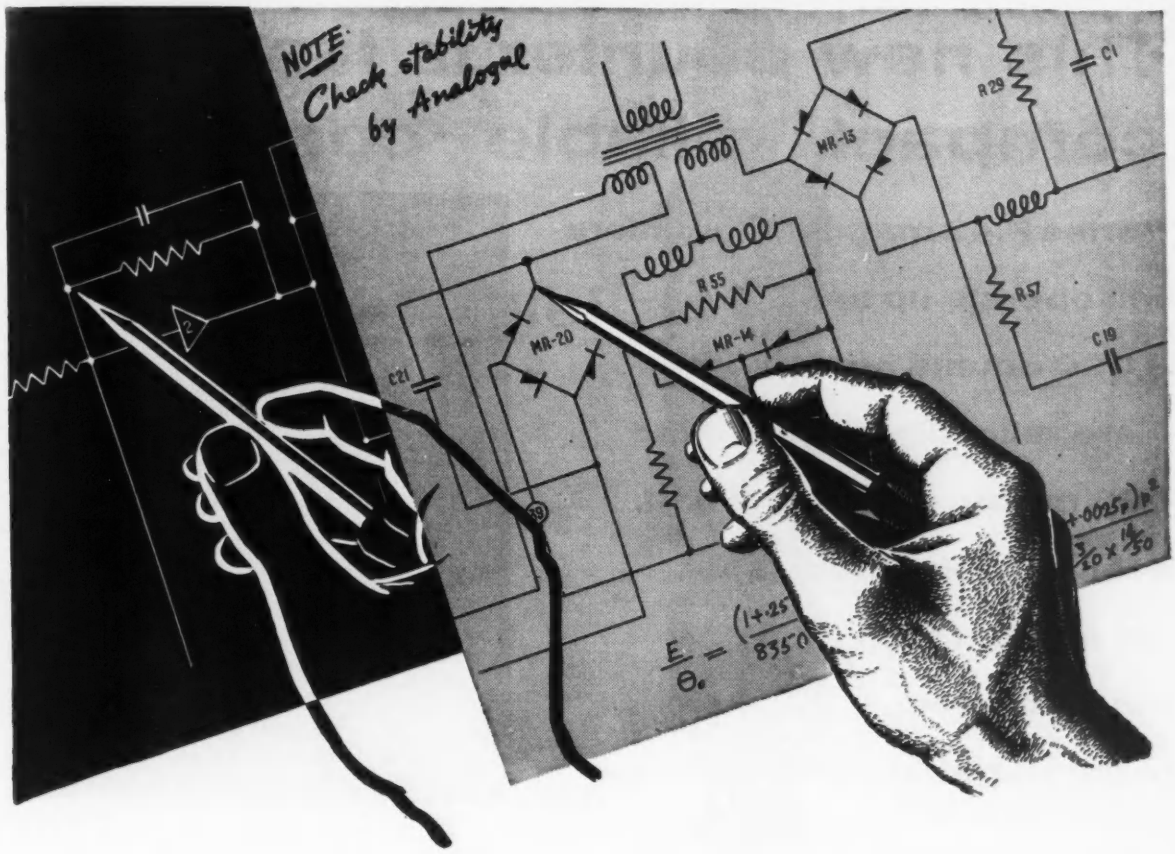

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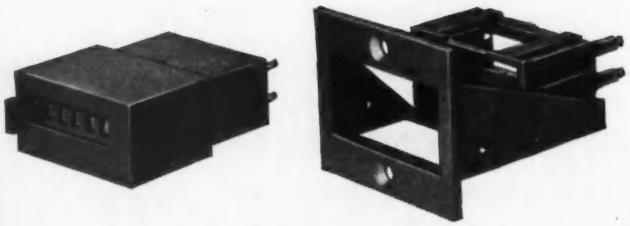

Flexibility shown by plug-in flush mounting and dovetailed stack

The Hengstler Series F.43 electro-magnetic counter (patents pending) is manufactured in Western Germany by J. Hengstler K.G., Sole agents for this counter in the U.K. are

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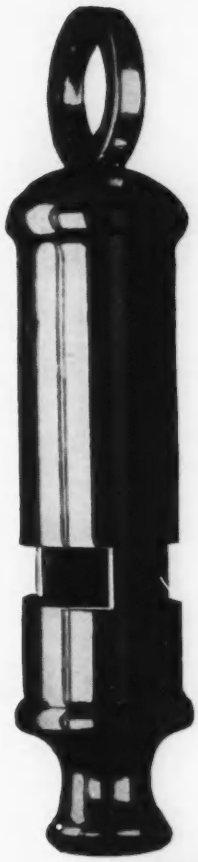
clean as a whistle!



A saying that has vastly diverse meanings. At home it means a good shine on things. In industry 'clean as a whistle' means absolute purity. Fairey have developed Microfilters that will filter materials as varied in viscosity as molten plastic and gas to 2½ *micron purity*, and remain efficient through very wide temperature changes and under enormous pressure.

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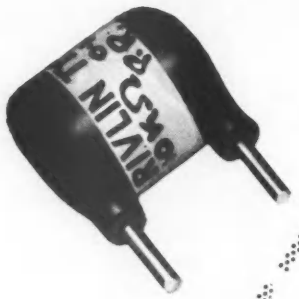

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Type 201, the newest precision wirewound resistor can be plugged into an Electro Methods type D2 socket. Gold-plated phosphor bronze pins ensure strength with consistent low ohmic contact resistance, while the tough resin encapsulation will withstand extremes of temperature and humidity.

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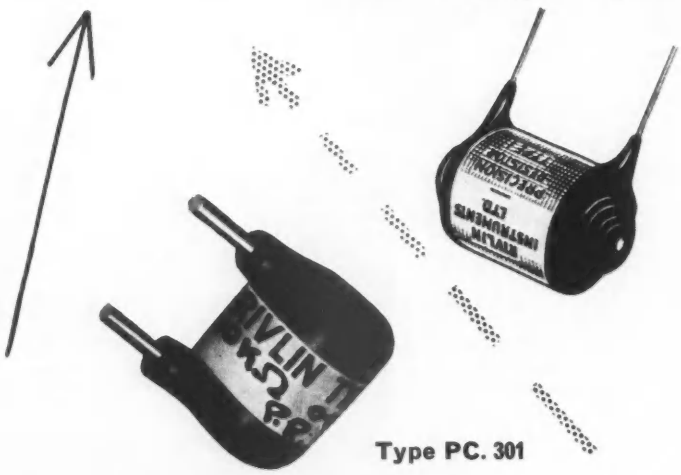

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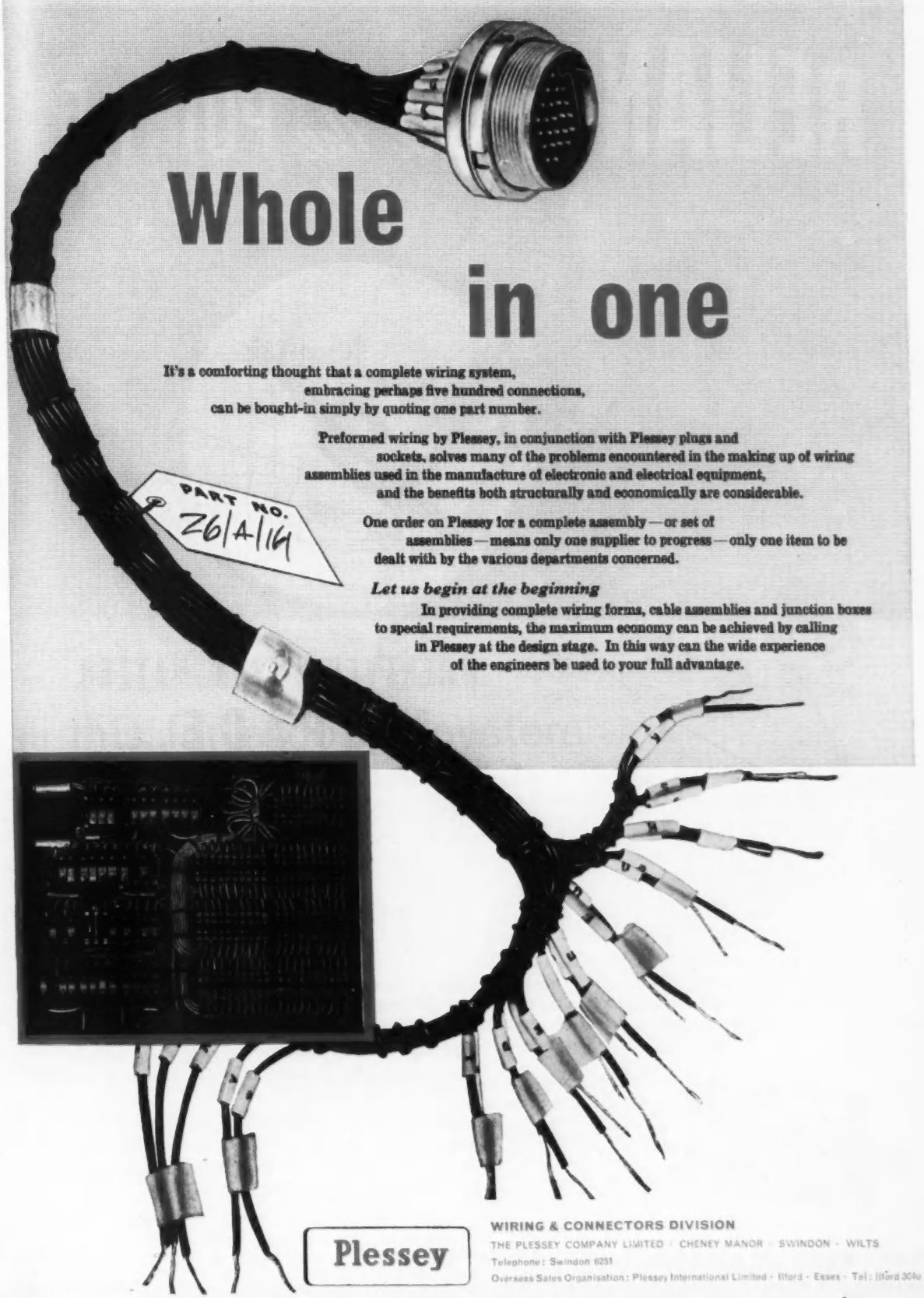

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CW 11

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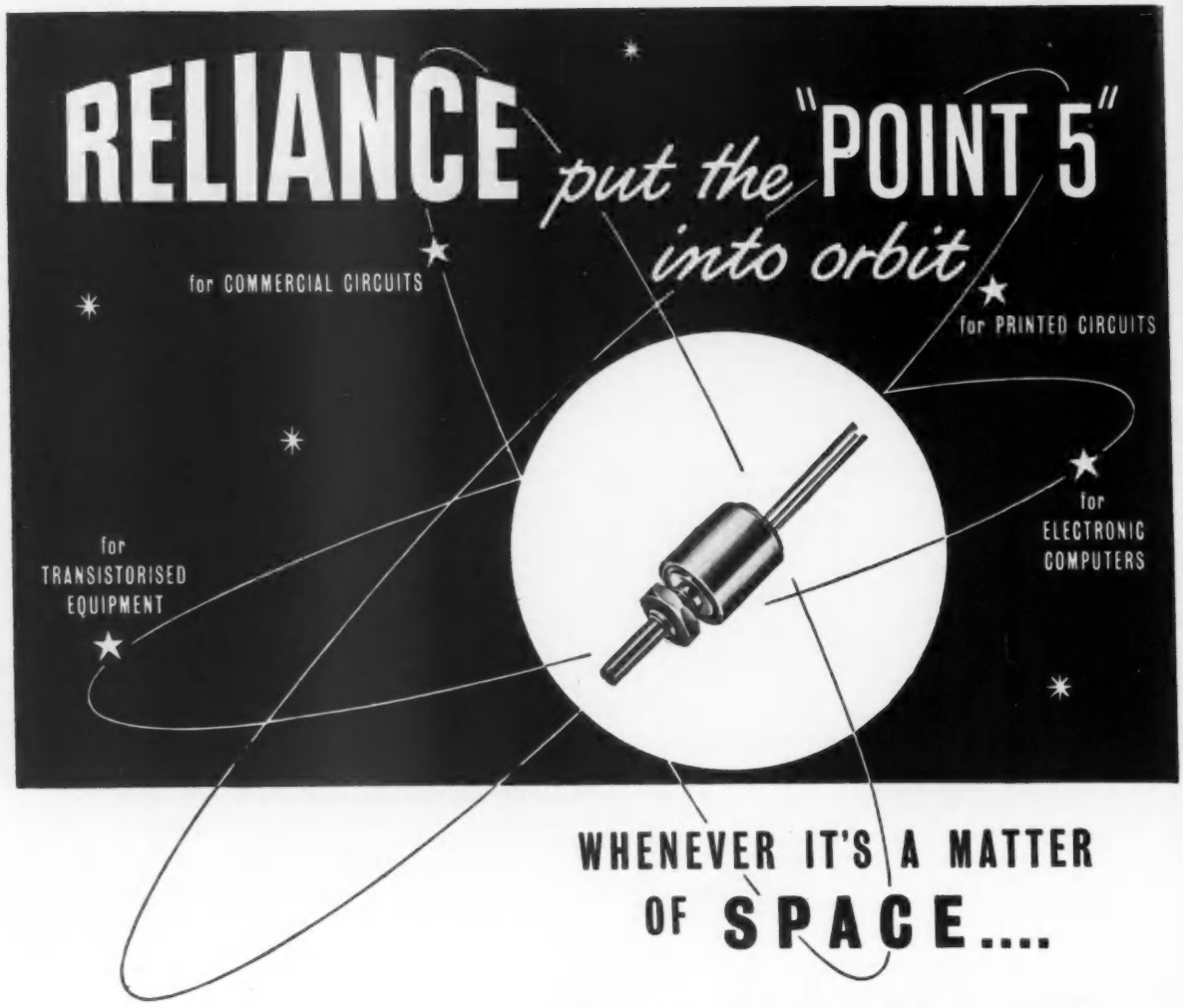

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Whenever it's a matter of space this new *wire-wound* potentiometer, of only 0.5 in diameter and weighing only 7 grammes, will eliminate your difficulty.

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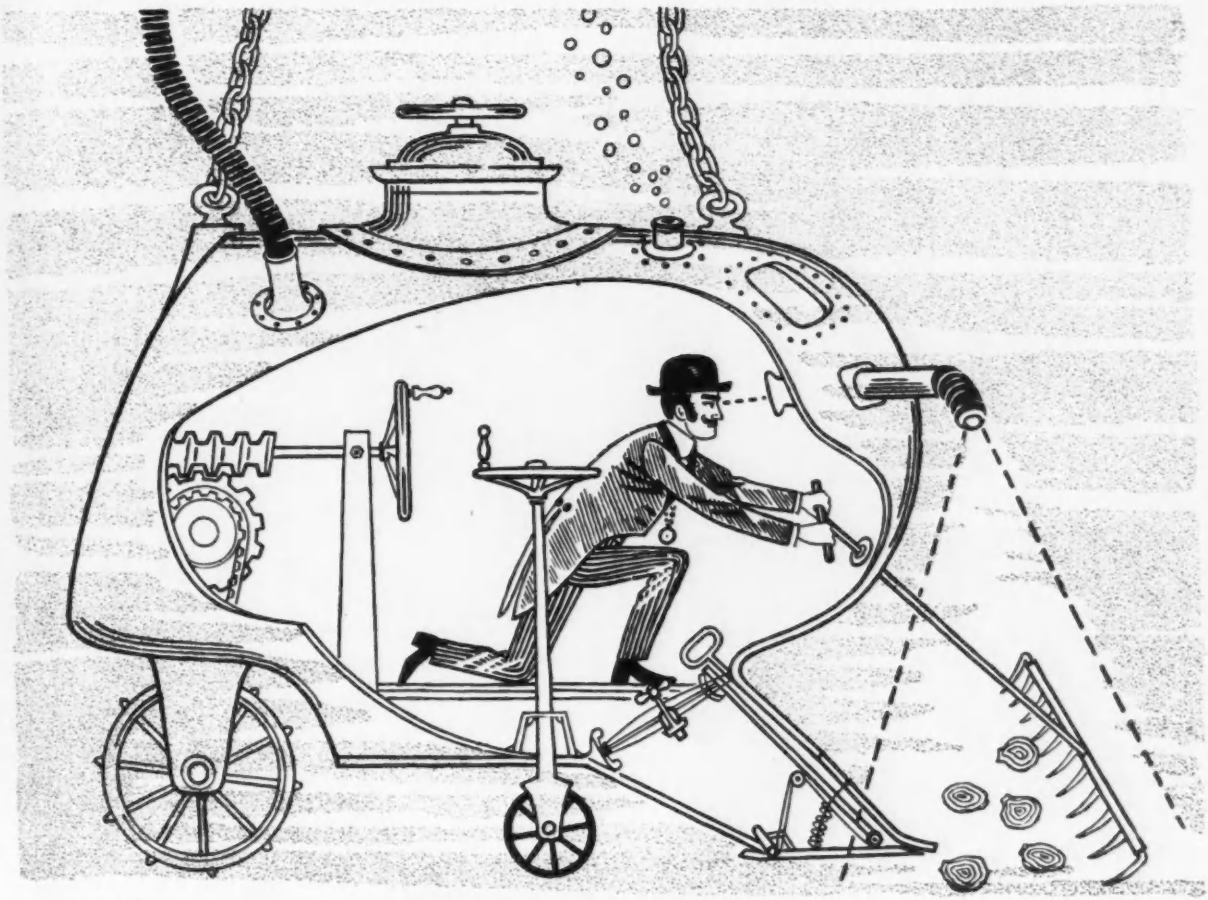

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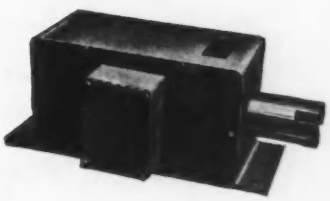

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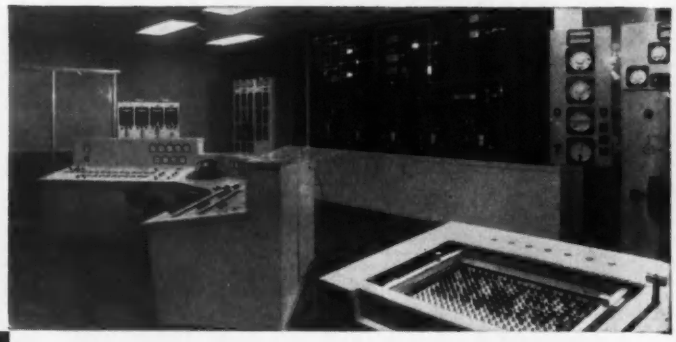

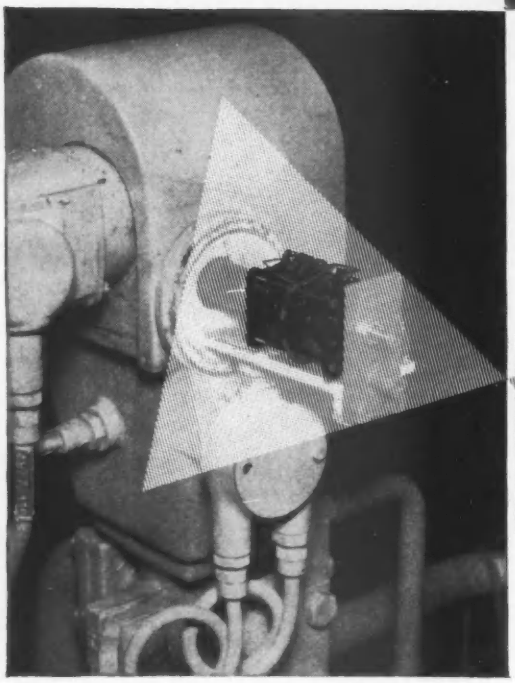

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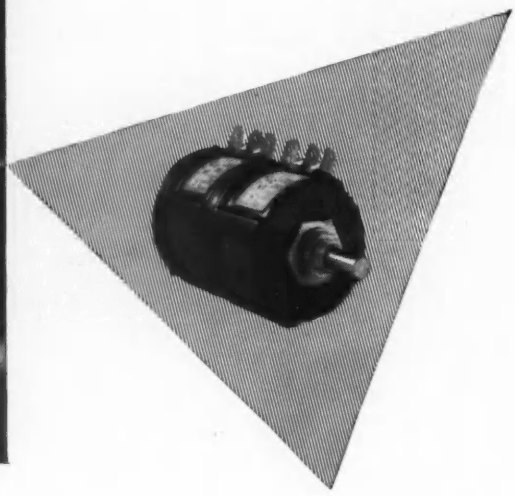
for valve position control and generation of control signals.



Above: Series 'C' Helipot, two gang unit, mounted on a large control valve at the Rolls-Royce Altitude Test Plant, Derby. These potentiometers ensure an accurate and fine control of temperature and pressure in the engine test cells, corresponding to the desired altitude conditions.

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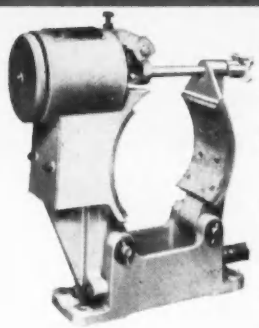

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Sizes 2" to 30"
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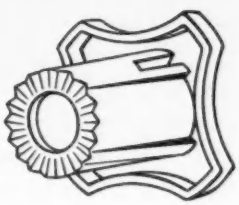

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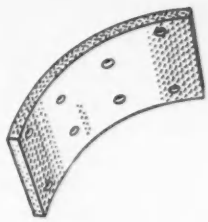

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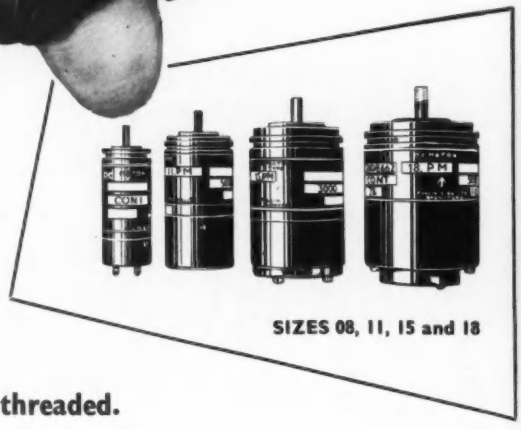

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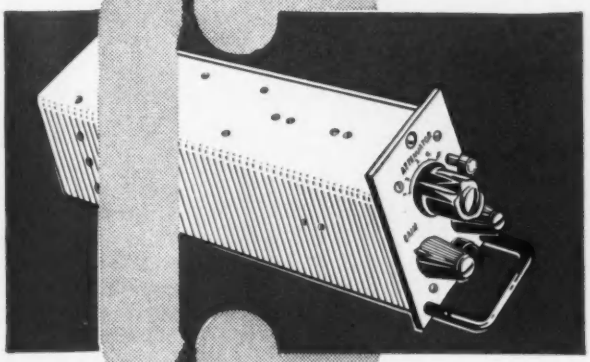

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The measurement of strain is an increasingly important task in modern industrial planning and in a multitude of operations. One major problem is the amplification of strain gauge signals and the A.W.E. Transistor Galvanometer Amplifier is ideally suited for this purpose. □ The T.G.A. is one unit of a specially developed recording system which has a wide application in strain gauge pressure measurement and the general instrumentation field. □ The Amplifier is a modular unit, designed to drive viscously damped galvanometers which normally have a resistance of 50 ohms and a working range of DC to 2 Kc/s in Frequency. □ Do your strain gauge problems include measurements up to 750°C? We can supply 'Avro' units to meet these stringent requirements:— Write to us for details.

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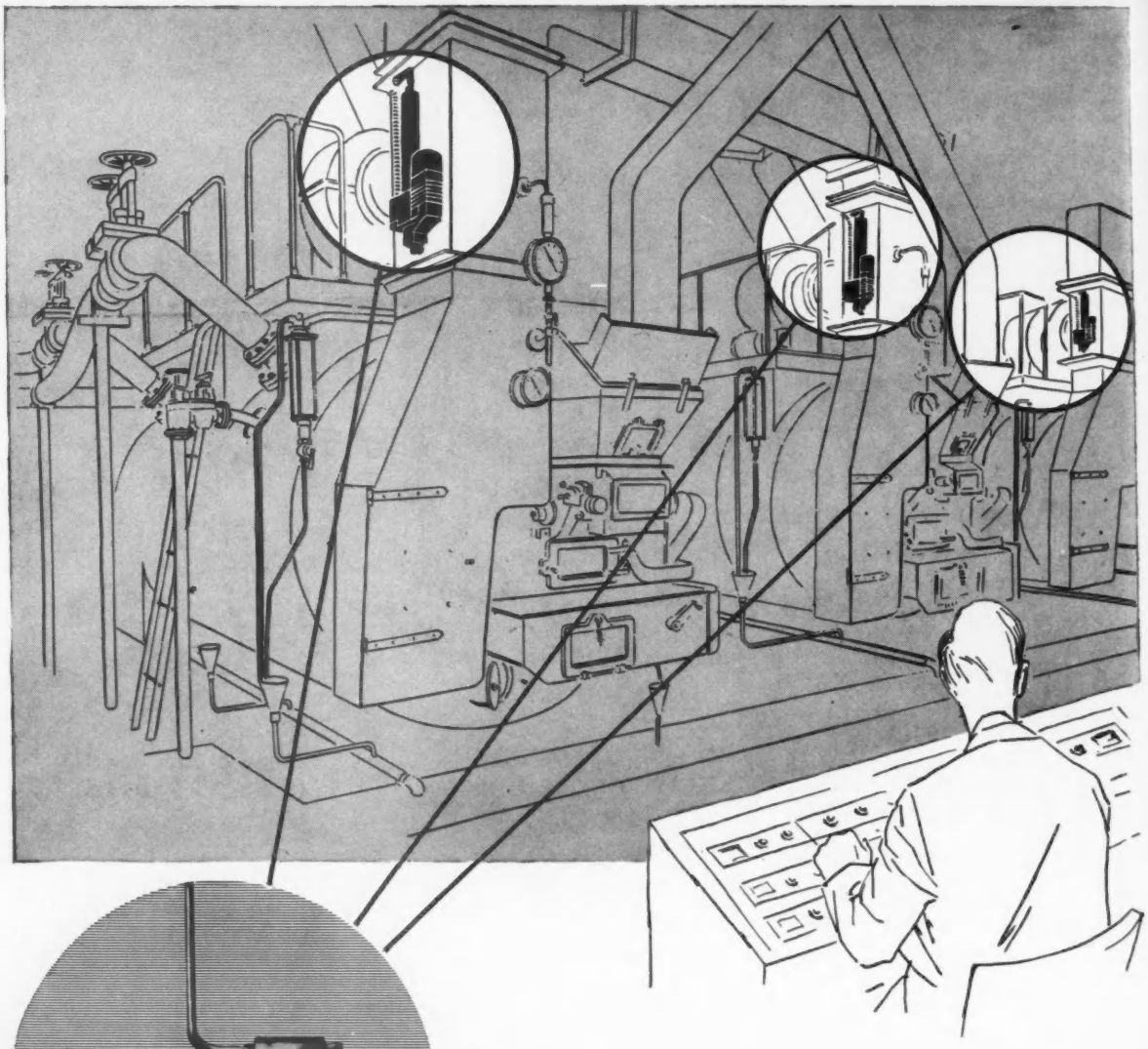
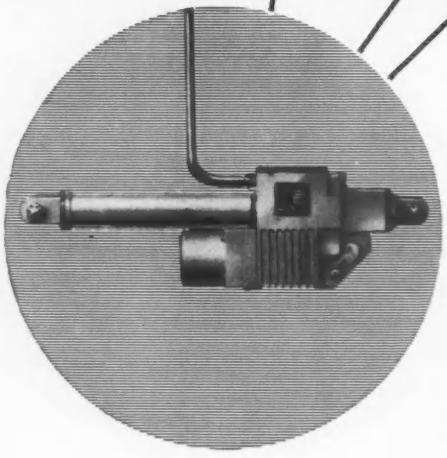
That is why, for example, all our articles begin and end on full pages* without breaks; why graphs and diagrams are so meticulously drawn and captioned; why *Control* looks so different from any other technical magazine in the world.

*This easy-to-file layout system is specially useful to engineers who maintain private reference files. A pre-paid subscription card will be found facing page 183.





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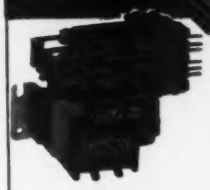
LONDEX

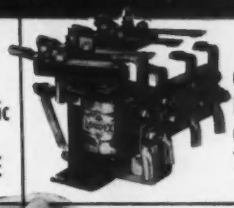
Range of Relays



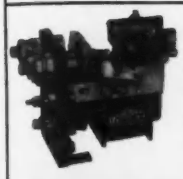
Multiple Contact Type LF

Mercury Switch Ty

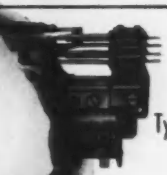
Electronic Relay Type RE



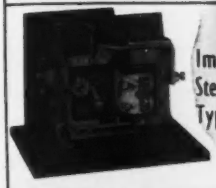
General Purpose Contactor Type LB



Heavy Current Contact Type



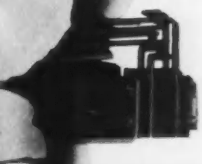
Double Action Types LF/D LQA/D



Impulse Stepping Type PS/

Relay FOR THE MONTH

Write for list 178 containing full details



Midget for A.C. or D.C.

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Type

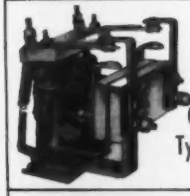
Miniature D.C 24v. Max. Coil Type ST

Co-axial Relay Type SCX

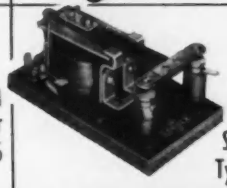
Relay (Sealed) Type GCX

Aircraft Type 411

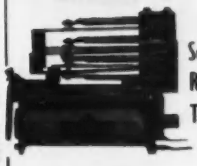
Aerial Change-over Type AECO.4



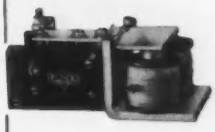
Aerial Change-over Type AECO. 15



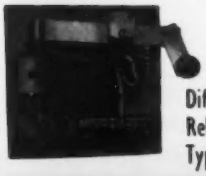
High Voltage Switching Type 9648



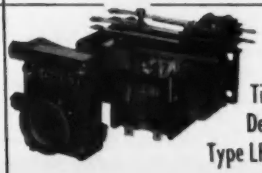
Sensitive D.C. Relay Type KR.



Sensitive Relay Type SSR



Differential Relay Type HS



Time Delay Type LF/T1

Time Delay Type LQA/T3

D.C. Bus-bar Relay Type BZ

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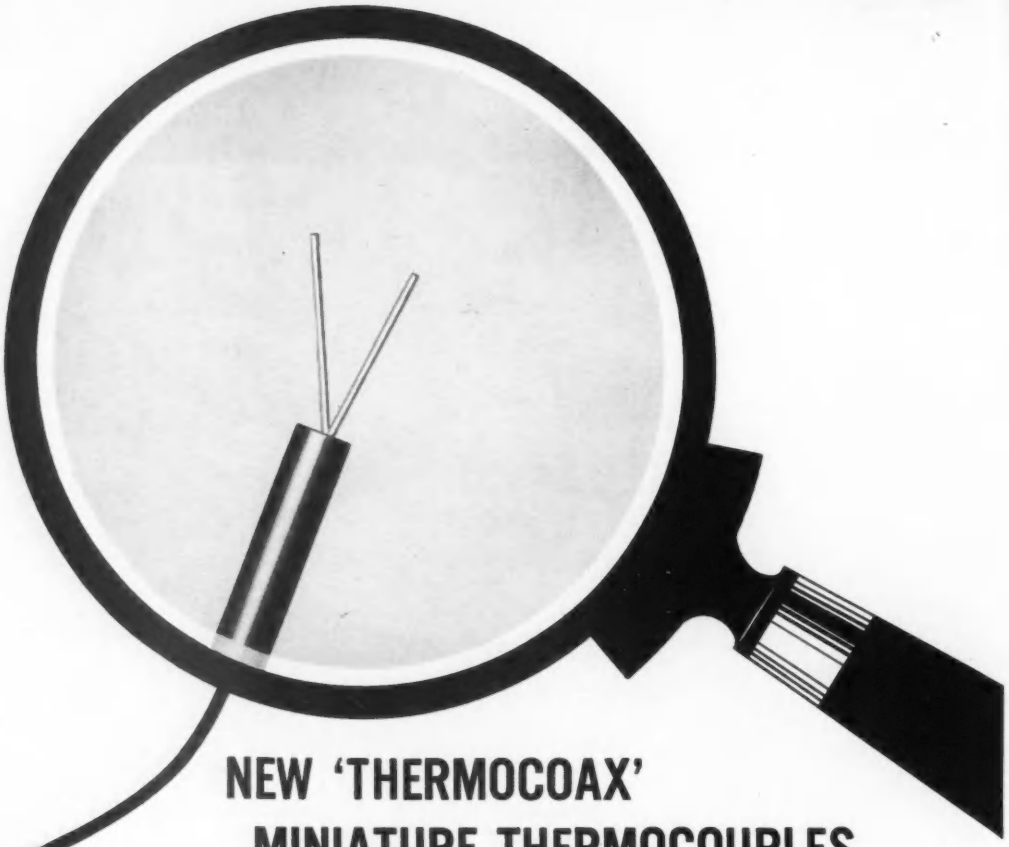

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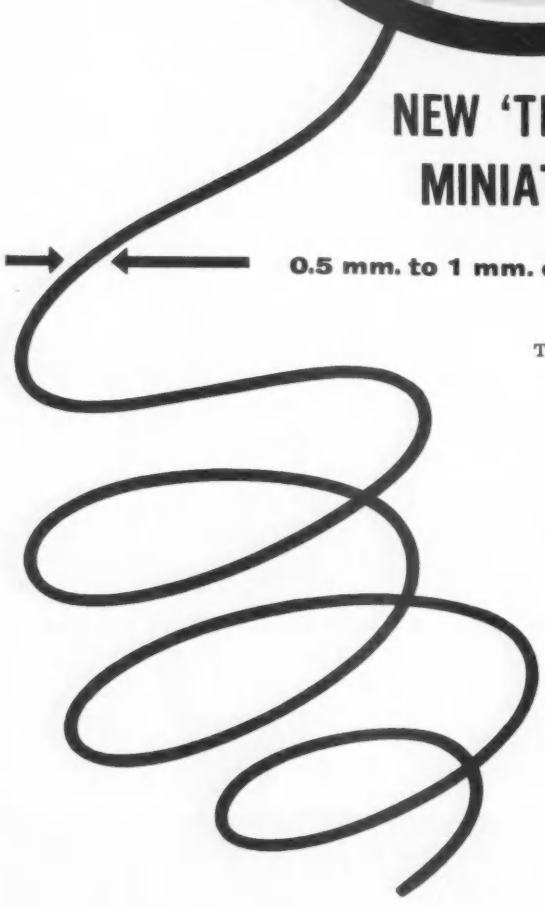
0.5 mm. to 1 mm. outside diameter



The latest THERMOCOAX ceramic-packed miniature thermocouple wires have outside diameters of 0.5 mm. and 1 mm. and can be bent on a radius of 2 mm. THERMOCOAX wire has great mechanical strength, especially against shock and high pressures, good stability at high temperatures and perfect insulation. Sharp bends can be made, the wire can be soldered or brazed to make gas-tight junctions, and the response time is very short. THERMOCOAX has a temperature range of 0-900°C. with an accuracy of within 2.8°C. up to 350°C. and 0.75% from 350°C. upwards. In nuclear applications it offers very small area for the capture of neutrons.

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(RCL0427)

MARCH 1960 VOL. 3 NO 21

CONTROL

The value of labour

TWO recent front-page news items that seemed to have something in common were the threatened strike by the railwaymen and the report of the Royal Commission on doctors' and dentists' salaries.* Both were concerned with pay, and both issues were complicated by questions of rank, status, precedence, differentials—call them what you will. In spite of their similarities, these two cases of labour trouble were poles apart in at least one respect; and we do not mean by this the very broad 'differential' between the salaries of the medicos and the wages of the railwaymen.

Though insulated to some extent from the changes against which businesses must protect themselves, governments or nationalized industries cannot ignore the techno-economic environment in which they exist. Sooner or later, navies take to steel and steam, turbines replace reciprocators, and telephone exchanges become automatic. Sometimes a business is very important to the nation, and then, if it lacks the ability to survive unaided, a government may reasonably take it over or protect it in some other way, at least for a time. If with this help the enterprise continues to fail, then the whole country suffers.

The railways are a case in point. At one time the spearhead of technical development, they have gradually declined from high drama to something that is not low farce only because it is no laughing matter. They have been successively bolstered up by the devices of monopoly and nationalization, but their fortunes have continued to sag. Yet only a few fanatics contend that we can entirely dispense with them.

One of the problems of twentieth-century civilization is the contrast between the ease with which its processes provide vehicles for individual transport, and the difficulty of devising suitable circuitry for the traffic to move along. Obviously this is a problem that the systems engineer can help to tackle. To him it will seem clear that the movements of nearly fifty-million individuals cannot be governed effectively if each individual can at any moment quite independently choose his position, velocity and acceleration in the tangled mesh of roads. This is apparent even to common sense, so in the past an element of order has been introduced by means of traffic lights, policemen, highway codes, and so on. A systems engineer, asked to devise an optimal network for the random motions of the individuals in a population, might well offer one in which there is a continuous and completely organized flow of vehicular traffic. (The escalator is of course a simple example of this sort of solution.) All movements on a rail network can be rigorously planned and regulated—if modern methods are used—and railways are therefore more suitable than roadways for automatic control.

But while others have been automatizing, the railways have tended to stick to the simpler methods of their forefathers. What a fearful object-lesson for industrial laggards! There, huge and unhappy, stumbles an industry that is still full of promise and potentiality, presenting a challenge that could readily be met by contemporary techniques. No doubt the expense would be great, for it would be the accumulated cost after many decades of neglect, but the result would be a rational system of public transport. We must hope that other components of British industry will heed this warning. Mechanization and automatization do not reduce the demand for labour—they raise the general level of skill that is required. Those enterprises that do not keep up with this progress therefore degrade their labour, and the consequence is decline and fall.

It is good that drudgery, either of muscle or of mind, should progressively disappear from human life, and we may assume for practical purposes that the highest level of human skill or intellect will always be above the highest sophistication of mechanism (in any case, if our creatures out-distance us they will replace us, and our ascendency in the scale of biological evolution will be over). At any point in history the highest demands for skill will fall on certain professions, and clearly they are the professionals at that time best entitled to material recognition. It is therefore right that engineers and medicos should be well rewarded in our day. To us, the saddest fact shown by the report of the Royal Commission is that professional engineers earn still less than doctors and dentists.

* *Report of the Royal Commission on Doctors' and Dentists' Remuneration, 1957–1960*, H.M. Stationery Office, price 15s.

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* No. 1 of a series to acquaint Engineers of the very practical advantages of PILOT Plug Gauges which *reduce* gauging costs.

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The gauging member is held in a split brass bush so that when wear takes place it may be—

(a) Reversed in the handle enabling the unworn end to be used.

(b) The worn portion ground off and the unworn portion advanced out of the handle.

The gauging member can thus be fed out like a lead pencil.

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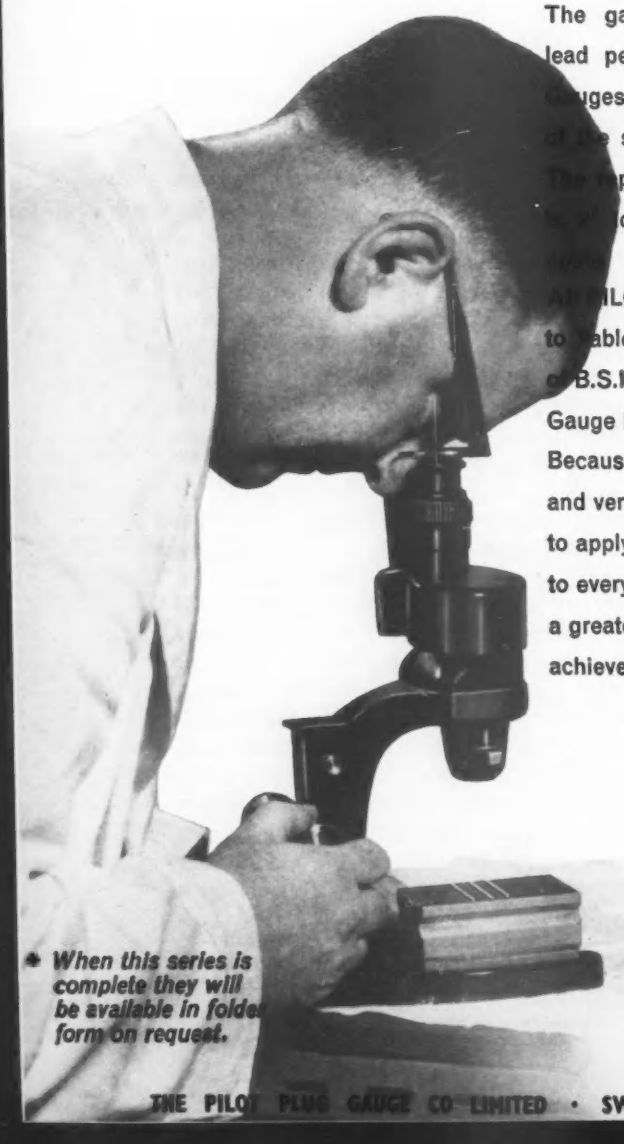

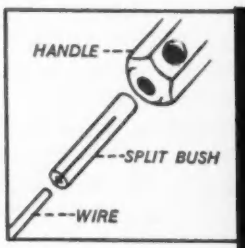

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LETTERS to the EDITOR

He who pays the piper ?

SIR: Mr. Toothill's article 'The Development Lark' in the February issue of CONTROL seems to be politically very provocative. Without recapitulating his case, he is effectively saying that development now-a-days is very costly, and that if not related to the direct profit of any company concerned must lead to an overall loss for that company. It is obvious that a country the size of Great Britain will find it difficult to compete with the technological status of the U.S.A. and the U.S.S.R., since in both countries considerable assistance is given by the State.

If we are to attempt to pit our skill against these two giants, then vast sums of money must be made available from the public kitty. In the case of a research programme that comes to nought, there seems no reason why the public should not foot the bill. In the case of a development programme which enhances a company's prestige and profit-making ability by an appreciable amount, there seems no reason why the public should not share in these increased profits. I am certain that Toothill is not making such an advocacy, but his whole article, particularly if one reads it with a few thoughts about machine tools, is a plea for the nationalization of those industries which require vast capital sums for development. In fact, it has been shown time and time again over the last few weeks that private investment cannot, for one moment, cope with the development and expansion of the major industries.

Wolverhampton JAMES LEWIN

Navigators losing way

SIR: Mr. K. C. Garner's letter in the January issue of CONTROL demonstrates most clearly that the College of Aeronautics fully appreciates the needs to integrate flying controls with positional navigation. Indeed, engineers generally and servo engineers in particular seem to accept this integration.

Nevertheless, it would seem that in this respect control engineering is ahead of navigation. To quote an example, I know of no text book on navigation which deals with flying instruments apart from their application to verifying position.

My comments were intended to suggest that control engineering is making a contribution to navigation thought. Indeed, it may be that control engineering philosophy can make contributions to thought in many other fields. I would quote, for example, Administration. Most of us know the instability that may arise when 'the Boss' applies too much gain!

Sperry Gyroscope Co. Ltd. E. W. ANDERSON

Tachometric accuracy

SIR: Having read with interest the article "Linear Tachometry for Machine Tools" by Messrs. M. J. C. Fowell and A. Cowley,* I would like to draw attention to the fact that precision A.C. integrating tachometers can be obtained in production quantities with an accuracy of 0·2%, and extremely low null voltages with negligible phase shift.

Mr. Fowell's article states that the best order of accuracy obtainable for A.C. Induction Tachometers is 2%.

Ketay Ltd. E. BROWN

* *This article appeared in January's* CONTROL. *We should like to apologize for the misquotation of Mr. Fowell's initials on page 80 of that issue. They were correctly stated on page 3, and are 'E.J.C.', not 'M.J.C.'*—EDITOR.

● *Messrs. Fowell and Cowley write:*

'The precision tachometers that Mr. Brown of Ketay Ltd. refers to, were known to have been available in Great Britain at the time the article was written.

In order to obtain the quoted accuracy the makers state that it is necessary to stabilize the frequency of the reference power input to one part in 4000. This degree of stabilization of supply frequency is not obtained without expensive control equipment.

The figure of 2% expected accuracy quoted in the article was arrived at considering a 1% supply frequency variation with an induction tachometer of the same order of accuracy, and other inaccuracies in the velocity measuring system as a whole.

We should like to correct an error made in our original script. On page 81 under the heading Piezo-electric accelerometers *the minimum measurable acceleration should read* 'approximately 0·002 *g*'.

We should also like to refer your readers to an article published in your September 1959 issue under 'Ideas Applied'. The author, E. M. Dunstan of the Department of Electrical Engineering at Manchester University describes a high-precision d.c. tachometer, the principle of operation being the determination of the speed of a conducting cylinder by the measurement of the quadrature field set up as it passes through a primary magnetic field.

The invention is the subject of British Patent Application No. 2818/56, the rights of which are owned by the National Research Development Corporation.'

Further details of this tachometer were given in 'Ideas Applied' last month.—EDITOR.

PUBLISHER'S COLUMN

A chance to fraternize

One subject that we see cropping up time and again in CONTROL *is the increasingly important part that is being played in the control engineering world by the Russians. It is plain enough to see why. Not only are Soviet scientists and technologists doing practical things like hurling heavy masses into space under superlative control, but they are also advancing significantly in the mathematics of control theory.*

A few months ago it was urged by a contributor that control engineers should take up the study of Russian. One of our Directors speaks it fluently, but we suspect that our editorial staff do not relish the thought of learning a new and difficult language at this point in their careers!

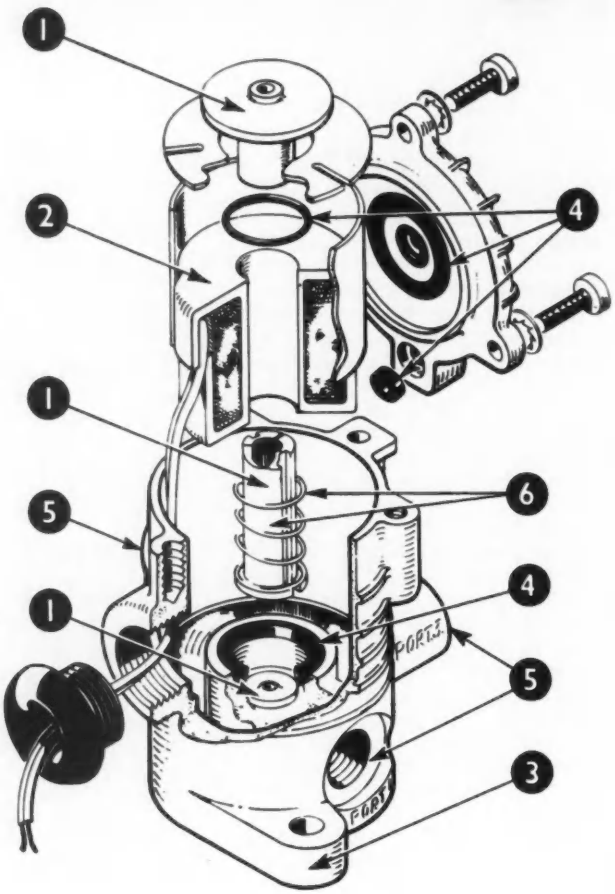
Judging by the remarks made at a recent meeting on Soviet automation (which we see reported in this issue of CONTROL), *Russian progress is feared by some as a potential threat to British trade. This may be a pessimistic view, and we hope it is, but it is well to be wary.*

A grand opportunity is coming up in a few months' time for Western control engineers to fraternize with their Russian counterparts, when the I.F.A.C. Congress will be taking place in Moscow. It is interesting to see that the provisional list of British delegates, which includes the Editor, already numbers more than seventy.

Detailed design and precision machining explain

MAXAM

quality and unfailing operation



Exploded for production engineers to appreciate its superior reliability, here is a pilot solenoid valve by MAXAM:-

1. ***Seats and Plunger*** — manufactured from plastic iron, heat-treated to provide maximum wear-resistance consistent with optimum electrical characteristics.
2. ***Encapsulated Coil*** — each one subjected to a 24-hour water immersion test before assembly. Available in a wide range of AC and DC voltages. Heat dissipation assisted by controlled medium passing through centre of coil.
3. ***Mounting Attachments*** — cast as an integral part of valve body.
4. ***Seals*** — of special synthetic rubber compound which resists the action of specified liquids and gases.
5. ***Operation*** — the valve can be arranged for two or three-way normally open, or normally closed operation.
6. ***Only 2 Moving Components*** — movement is confined to the plunger and spring, reducing wear (and consequently maintenance) to the minimum.

* ***Manifold Mounting*** — the valve body base can be drilled (drill-point recesses are provided) for mounting on a machined face.

* ***Compactness*** — overall height of the valve is only $3\frac{1}{16}$".

* ***Operating Pressures*** — range up to 250 p.s.i. depending on the valve arrangement and orifice size.

The design above is typical of the meticulous attention to detail and the superior care taken to ensure that MAXAM controls and air/hydraulic components shall work infallibly for as long as possible on the minimum upkeep cost. The whole assembly complies with the MAXAM emphasis on quality and reliability.

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VIEWPOINT

An open letter to the Minister for Science from Paul Goudime, Managing Director, Electronic Instruments and Past President of the Scientific Instrument Manufacturers' Association, on

HARNESSING OUR TALENTS

Dear Lord Hailsham,

I have just been reading your manifesto* in which you describe, in simple terms, how you hope to set about your task as the first Minister for Science. If I may say so, this is a brilliant exposé delivered with the skill, verve and wit of a 4th of June speech. You steer a fine course between the Scylla of the Universities and the Charybdis of Industry, with a neat bouquet thrown in passing to the Transport and General Workers' Union! Clearly, yours is a mammoth task and it must indeed be difficult to know where to begin. May I, therefore, as a manufacturer of scientific instruments, put forward with due temerity a problem which bedevils our industry and which, I feel sure, is common to many other branches of science?

My distinguished predecessors on this page have touched on almost every aspect for the betterment of British trade, prestige and leadership in world affairs. We have been urged by some, for closer co-operation between manufacturer and user; by others, for higher capital investment in the industry, and by yet others, for a quicker realization of the benefits to be gained by automation. All these are admirable sentiments and precepts with which no one can quarrel, but the fundamental problem which seems to have been overlooked is the shortage of scientific man-power and hence the vital importance of its proper use.

Of course, we cannot (to quote your own words) fling up 'clutches of satellites' or launch packs of nuclear submarines, however galling it may be for us to sit here and watch others enjoying them. But are we really doing all we can to help ourselves in making the best use of the talents we have available?

It would be difficult to find a piece of scientific equipment, whether of a simple or complex nature, which is not being duplicated or triplicated (or, in one case, multiplied by seventeen) with a consequent wastage of research effort and uneconomical production runs. This duplication not only extends from firm to firm, but can often be found in different departments of the same organization. If this state of affairs exists in industry, how much more must it prevail in the labyrinthine laboratories of our many universities and in the work of the multitudinous Government establishments which you control?

Here, I submit, is the first and most important task which your new Ministry can perform. Let it begin by making a highly confidential survey of all the research work being done in private firms and in universities and Government laboratories throughout the country. Collate the information in a register at 'Minerva House' and then send for the Managing Directors and the Heads of your Government Departments and present them with a digest of the facts. The results will astonish them! Follow this up with a series of private meetings and discussions and I believe that a new understanding would arise which could revolutionize our research potential and enable Britain's handful of scientists to match the achievements of the overwhelming numbers pouring from American and Soviet universities.

Of course, this will involve long and painstaking negotiations. Firms and laboratories will have to make considerable sacrifices and give up their pet projects to work on others which you, as Science Minister, will suggest . . . .

A pipe dream? Maybe. Or perhaps the seeds of the third industrial revolution.

Yours sincerely,

Paul Goudime

* *'The new Minister for Science explains his task'*; S.I.M.A. Bulletin; *Vol.* 13. *No.* 1 *(Jan.–Feb.* 60).

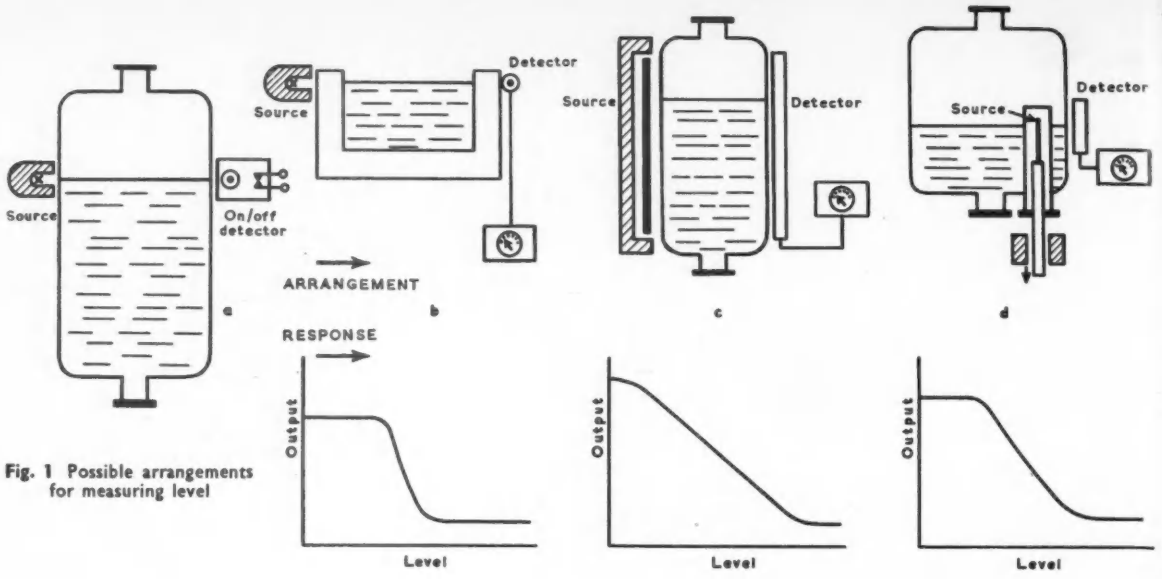


Fig. 1 Possible arrangements for measuring level

PART 1

A gamma-ray level-detector is an expensive but simple component that may sometimes lessen the cost of plant

Nucleonic measurement of level

by **E. W. JONES, B.SC., A.INST.P.**
Isotope Developments Ltd.

THE OPERATION OF NUCLEONIC LEVEL-INDICATORS depends on the fact that nuclear radiations are able to penetrate the solid walls of a vessel, suffering some absorption in the process, but are heavily attenuated by a large bulk of material inside the vessel. This penetrating power makes it possible to design level gauges in which all component parts are mounted entirely outside the vessel. For industrial process measurement and control, such a feature is extremely advantageous in that:

1. There is no need for special ports in the vessel to admit probes, floats, etc., and this cheapens the construction of pressure vessels, glass-lined tanks, etc.

2. The gauges can be installed and maintained while the plant is operating.

3. Gauge components do not have to be protected against corrosive fluids, abrasive powders, vibration, dirt, high temperature, or other difficult operating conditions which may exist within the vessel.

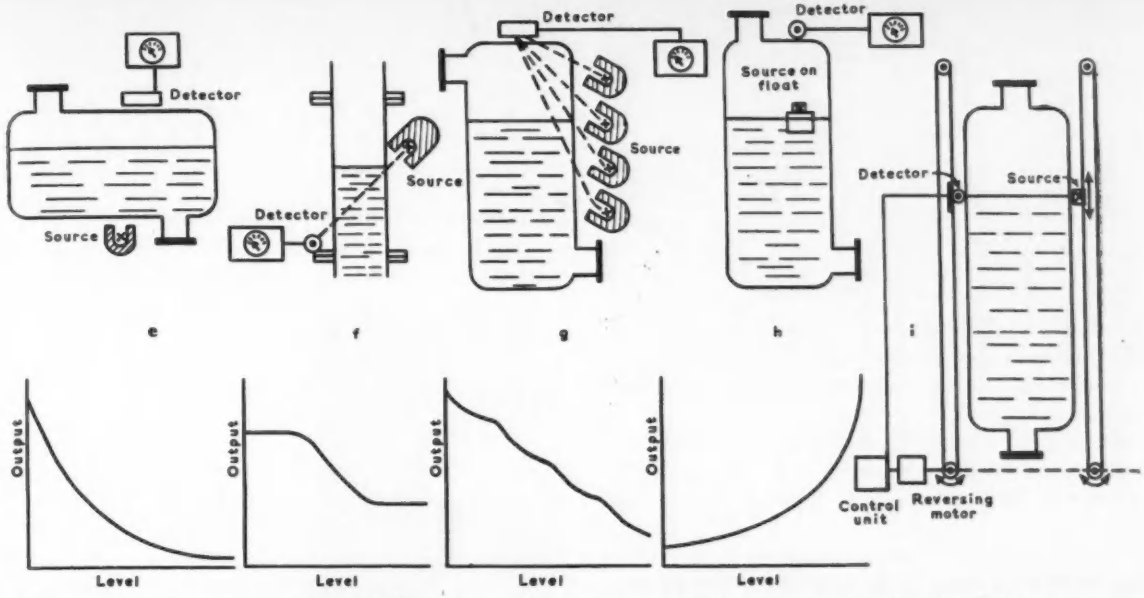
4. Instrument performance is satisfactory almost entirely without regard to the nature of the vessel's contents, provided that there is sufficient mass to absorb the radiation appreciably. The method can therefore be used with bubbling or agitated liquids, very viscous fluids, explosives, granular solids, fluidized powders, etc.

For these reasons, nucleonic indicators are finding increasing use in solving 'difficult' level-measurement problems on all types of industrial process plant. Although simple level measurements are made more economically by conventional methods (employing floats, electrical conductivity, capacity probes, photoelectric cells, etc.), the increasing cost of maintenance and installation is militating in favour of the nucleonic method.

Basic components and their arrangement

The basic components in the nucleonic level gauge are a long-lived radio-active source, radiation detector, and an electronic unit to convert the detector output into a useful electrical indicating or control signal.

These units can be applied to the vessel in a number of ways, as illustrated in Fig. 1. Owing to the size of commercially available components the method is particularly well suited to 'two-step' or 'on-off' control at a fixed level (Fig. 1a). For this purpose it is only necessary to mount a fixed point-source and detector on opposite sides of the vessel at the critical level. The increase of signal strength as the contents fall below this level is usually more than sufficient for reliable operation of a control relay. Thus the trip level of the relay can be set so that there is no further need for



adjustment over one source half-life (see page 90). Re-calibration is not required, but no access to the contents is necessary in order to determine the level at which control is taking place. Generally accuracy within $\pm \frac{1}{4}$ in. is easily achieved. Since the detector signal is only required to operate a relay, the associated circuit can be extremely simple and the electronic unit may be built into the detector housing to form a single self-contained unit (Fig. 2).

Where continuous indication of level over a finite range is required, the electronic unit is usually more complex and is mounted remote from the detector. With a source and detector of small dimensions mounted at the same horizontal level (Fig. 1b), the complete signal-change takes place over a small change of level (in practice about $\frac{1}{4}$ in.), so that within this limited range very small fluctuations can be detected. Such a system has been adopted as a standard method of indication and control of the level of molten glass in bottle-making plant. A cobalt-60 source and a water-cooled Geiger-Müller counter are mounted on the furnace feeder channel (as shown in Fig. 3) to indicate level fluctuations as small as a hundredth of an inch.

If it is desired to extend the vertical range of continuous level-indication, other geometrical arrangements may be employed. The use of a fixed linear source and linear detector (Fig. 1c) can give an approximately linear response over a range of about 2 ft. For a tank of reasonable dimensions, the radiation can be assumed to be cut off almost completely by the contents, so that the response is a function of the level, but not of the density, of the contents. Suitable linear sources of gamma radiation can be made from irradiated cobalt wire housed in a shielded source-holder as illustrated in Fig. 4, while the detector can be made from two or more Geiger-Müller counter tubes (Fig. 5).

Level indicators of this type find application on catalyst towers and other types of chemical plant. For ranges greater than 2 ft the arrangement becomes impracticable owing to the large mass of the source shield and the expense of the detector assembly. In large vessels it may be preferable to place the source in a pocket in the tank (Fig. 1d), and arrange to withdraw it into a shield when necessary. This complicates tank design, but simplifies source shielding.

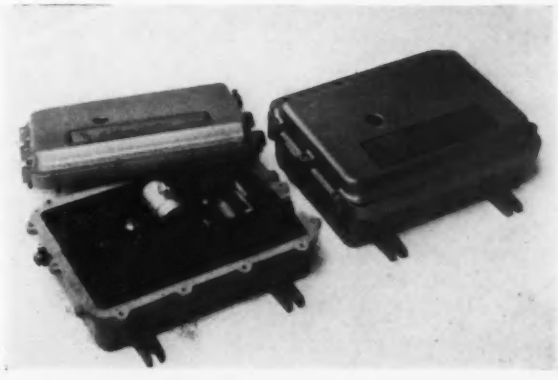
Measurement of level in terms of gamma-ray absorption, by directing the radiation vertically through the tank (Fig. 1e), is limited in practice to about 3–4 ft of water, and results in an exponential response giving poor accuracy over the high-level part of the range. Furthermore, readings depend on the density of contents.

The oblique scanning arrangement, illustrated in Fig. 1f, has proved useful in controlling the level of liquid-paper-pulp ingredients in vertical pipes of about 1 ft diameter. The non-linearity of response is not appreciable over ranges of 6–12 in.

The vertical range may be extended further, and made approximately linear, by the more elaborate arrangement shown in Fig. 1g, where a number of sources is employed. The strength of the sources is graded so that, when uncovered, each contributes the same signal strength at the detector. Ranges of up to 5 ft have been covered by this method, on plant such as bead catalyst towers.

The arrangement illustrated in Fig. 1h employs a

Fig. 2 Self-contained radiation-detector for on-off control of level



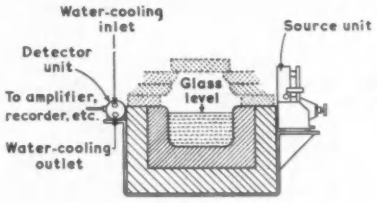


Fig. 3 Mounting of source and detector on glass feeder

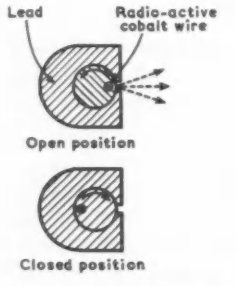
source mounted on a float within the vessel. Its only advantage over other systems employing floats is that no mechanical or electrical connexions need be brought through the tank walls.

In all the above continuous level-gauges, it is necessary to calibrate the instrument in the first place by making absolute determinations of level over the whole range.

In practice, the best way of covering a large vertical range of level-variation by the gamma-ray method is to employ an on-off detection system, and arrange for switching to control a motor drive so that both source and detector traverse vertically and follow automatically any changes in level (Fig. 1j).

In such a system it may easily be arranged that the traversing motor stops when source and detector are opposite the top surface of the contents, and does not hunt or move until the level changes. The motor system can operate a remote level-indicator. To simplify the mechanical traversing gear in large vessels, it is usual to fit the gauge to a stand-pipe of suitable dimensions leading off the side of the vessel. A level gauge of this type is illustrated in Fig. 6.

Fig. 4 Below, horizontal section on shield designed for linear source. Right, linear shield for gamma-ray source used in continuous level-indicator



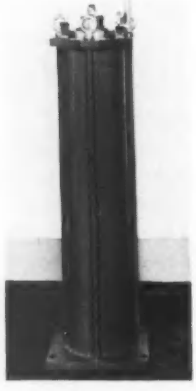


Fig. 5 Flame-proof linear detector-unit employing G.-M. tubes

Selection of the source

The radio-active source must be chosen so that its radiation can penetrate the vessel walls easily, but will be attenuated appreciably by the contents. It is required also to have a long half-life (time to decay to half activity—measured from any starting time) so that replacement or re-calibration is rarely necessary.

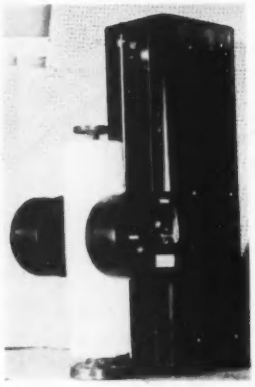


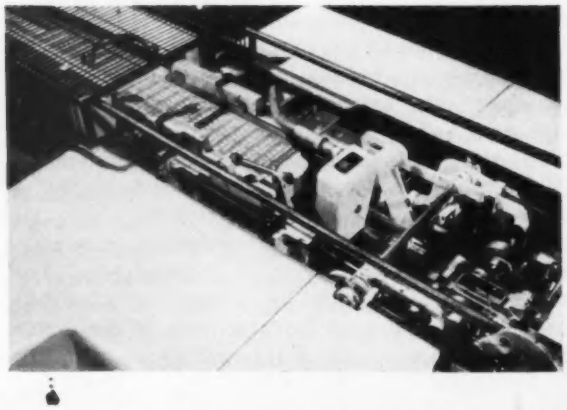
Fig. 6 Traversing system for continuous level-indication in stand-pipe

Where the vessel is small, with very thin walls, beta-ray sources may be used, the most popular choice being yttrium-90 in equilibrium with strontium-90. This gives a half-life of 25 years and maximum beta energy of 2·2 MeV. The maximum range of penetration of the beta rays is about 0·05 in. of steel or 0·4 in. of water. Such sources are used on plant for making non-alcoholic beverages where it is necessary to control the level of sticky liquids (cordials, syrups or essences) in a vertical pipe. Since the source and detector are mounted outside the tube, there are no adhesion problems and no difficulties in internal cleaning or sterilization.

Beta-ray sources are also used to check the filling level of soap-powder cartons, beer cans, tooth-paste tubes and other small containers on high-speed packing machines. An on-off system is used, coupled to an automatic mechanism for rejection of under-filled containers (see Fig. 7).

To be continued

Fig. 7 Inspection on tooth-paste packing machine. The detector, containing a G.-M. tube, is in the middle



Control is necessary at every stage, and automatic control is used in the preparation and burning stages of cement manufacture

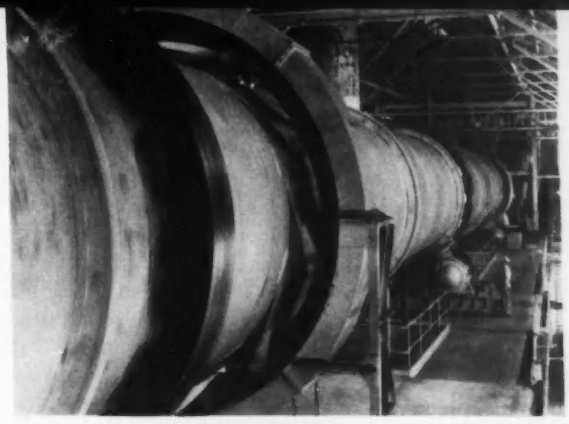


Fig. 1 Rotary kiln

Automatic control in the cement industry

by **G. FIELD** *and* **S. R. BARKER**
Associated Portland Cement Manufacturers Ltd.

PORTLAND CEMENT IS THE PRODUCT OBTAINED BY BURNing at a temperature of 1400–1500°C a chemically proportioned mixture of finely ground chalk (or limestone) and clay (or shale), cooling, and grinding the resultant clinker with gypsum. In what is known as the 'wet' process the raw materials are ground in the form of a slurry containing about 40% of water and are fed directly to a rotary kiln where they are successively dried, decomposed and finally combined chemically into cement compounds. In the 'dry' and 'semi-dry' processes the raw materials are dried and ground, and are normally fed to a pre-heater either as a powder or as moist nodules before being discharged into a rotary kiln for final burning. The majority of cement clinker in the world is manufactured by one of these three processes, all of which use a rotary kiln (illustrated in Fig. 1) for the final burning process. The kilns are normally fired by means of pulverized coal or oil, but where it is readily available, natural gas has been used.

Control variables

Control is necessary at all stages of manufacture. The major items requiring control are as follows:

A. Preparation of raw material
1. Chemical composition
2. Fineness of grinding
3. Moisture content of slurry or nodules.

B. Burning of raw material
4. Feed rate to kiln or pre-heater
5. Final burning temperature
6. Fuel and air supply to kiln.

C. Grinding of clinker
7. Correct proportions of clinker and gypsum
8. Fineness of finished cement.

Many of these items are controlled manually with appropriate instrumentation, but some automatic control is used in the preparation and burning stages.

Automatic drying and grinding of raw materials

In the dry and semi-dry processes the raw materials are fed to air-swept mills which dry, grind and classify the product to the required degree of fineness, the over-

Fig. 2a Control system for drying and grinding of raw materials

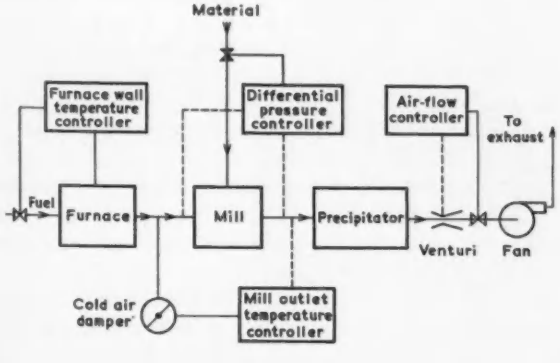
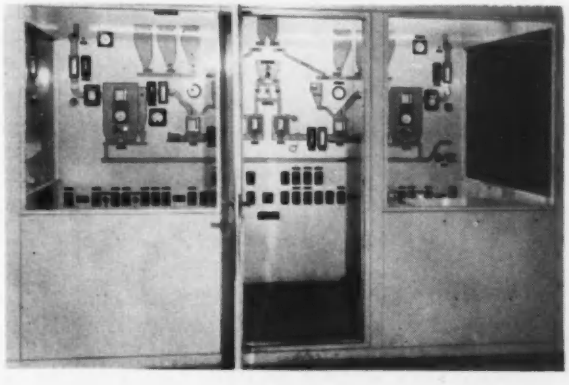


Fig. 2b Control panel



size product from the classifier being returned to the mill for further grinding. By keeping a constant amount of material in the mill at any given air-flow and classifier-setting, it is possible to operate continuously at any desired level of fineness. The drop in static pressure of the air flowing through the mill is a measure of the amount of material in the mill and can be used to control the feed rate. The correct amount of heat required for drying the raw materials is obtained by controlling the temperature of the gases leaving the mill. Fig. 2a indicates the control system used, part of which is automatic and part manual, but all of which can be made automatic. Fig. 2b shows the control panel

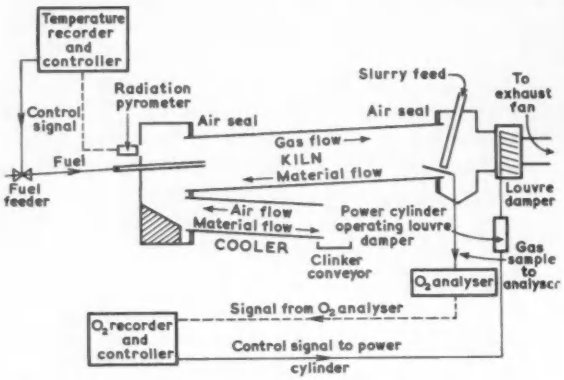


Fig. 3 Control system where conditions permit use of radiation pyrometer

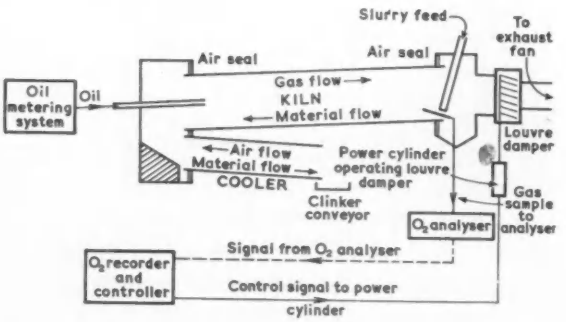


Fig. 4 Control system for use with oil firing

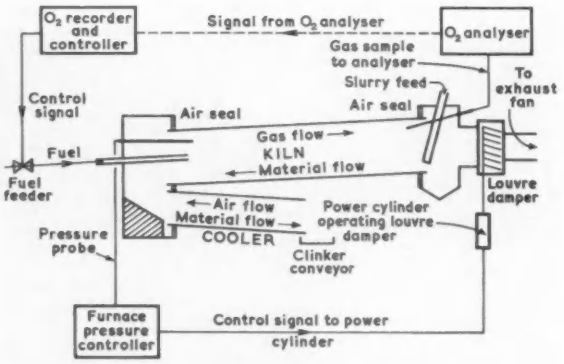


Fig. 5 Control system for use with pulverized coal

Fig. 6 Pressure damper operated by power cylinder

for this plant. The essential features are:

1. The air-flow through the mill is metered by an orifice or venturi and kept constant by controlling the exhaust fan speed or damper.
2. The differential static pressure across the mill is used to control the rate of feed to the mill.
3. The temperature of the gases leaving the mill is used to control a cold air damper on the inlet side of the mill.
4. The temperature of the furnace walls is used to control the input of fuel to the furnace.

Automatic burning in rotary kilns

For a given raw material there is an optimum final temperature to which it should be heated to give a satisfactory product. In certain kilns it is possible to control this temperature directly by means of a total radiation pyrometer sighted on to the material in the burning zone. Fig. 3 indicates such a system. In this the fuel input is controlled from the pyrometer signal, and the total air required for the combustion of the fuel is controlled from the oxygen content of the exhaust gases.

On many kilns, however, a total radiation pyrometer cannot be used successfully owing to the presence of a variable quantity of suspended clinker dust which absorbs part of the radiation emitted by the material in the burning zone. Under these circumstances, the optimum burning temperature has to be obtained indirectly by introducing the correct amount of heat for the type and quantity of raw materials fed to the kiln. This is equivalent to supplying a constant heat input to any kiln supplied with a constant input of raw materials. A constant heat input can obviously be obtained either by metering the fuel and controlling the necessary amount of combustion air from the gas analysis (see Fig. 4) or by metering the air and controlling the fuel input from the gas analysis (see Fig. 5). The system illustrated in Fig. 4 can only be used when the fuel quality remains constant, as is the case with oil or natural gas, whereas

the system illustrated in Fig. 5 is necessary with a fuel of variable quality such as coal. The essential features of the latter system are:

1. The quantity of air supplied to the kiln is obtained from the static pressure of the air in the kiln hood measured by means of a sensitive furnace pressure controller.
2. The signal from the controller is used to actuate a power cylinder which operates the exhaust damper (see Fig. 6) thereby keeping the air-flow constant at the desired level.
3. The kiln exit gases are continuously sampled and analysed for oxygen content, and this information is fed to a recorder/controller.
4. The signal from the controller maintains the fuel input at a level which gives the desired oxygen content of the exit gas.

The recorders and control equipment (see Fig. 7) are housed in a dust-free atmosphere and a pressurized instrument cabin is often used for this purpose.

Benefits of automatic control

The advantages of automatic control are that it is easier to maintain a good quality of product, that it lowers the maintenance costs because of steadier running conditions, and that it saves fuel.

Figs. 8a and 8b illustrate records of the oxygen content and air supply to the kiln operating under manual and automatic control. The upper right-hand instrument is an oxygen indicator-recorder/controller with a range from 0 to 2% oxygen. The other two instruments are the furnace pressure indicator/controller and the pressure recorder.

On this kiln the optimum amount of excess air for a minimum fuel consumption is that given by an oxygen content of about 0·5% in the exit gases. Fuel is wasted both above and below this value, but more so at lower levels. It will be seen that to avoid insufficiency of air, on manual control the oxygen content averages about 1%, with a range of ± 1% due mainly to fluctuations in fuel quality. On automatic control, however, it is possible to operate at the optimum level of 0·5% of oxygen with a variation of about ± 0·1%.

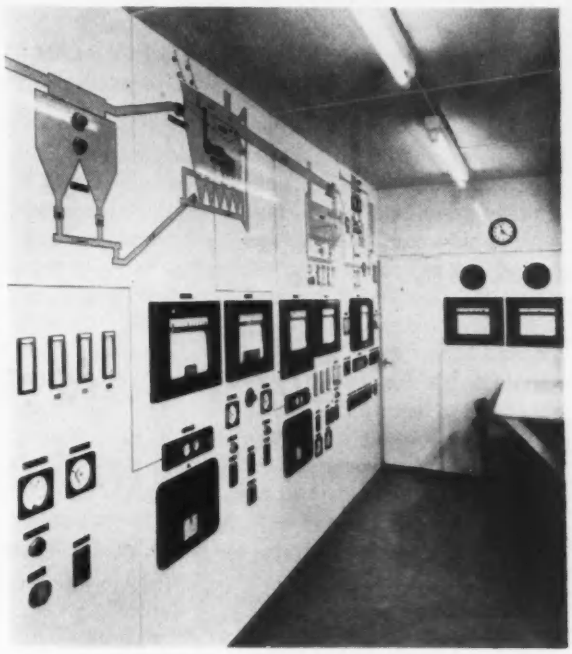


Fig. 7 Recorders and control equipment in dust-free atmosphere

Future developments

Refinements in the existing methods of automatic control are continually being investigated, together with new methods for all stages of manufacture. In particular it is hoped that automatic control equipment may be used for the adjustment of the chemical composition and moisture content of the slurry.

Fig. 8a Manual control—large fluctuations

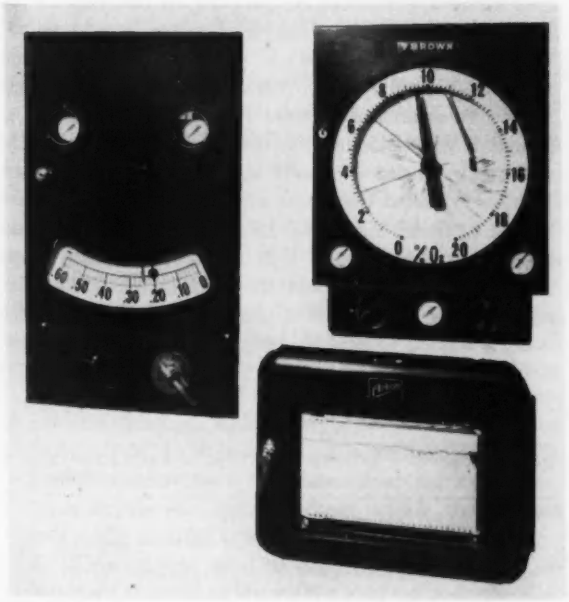
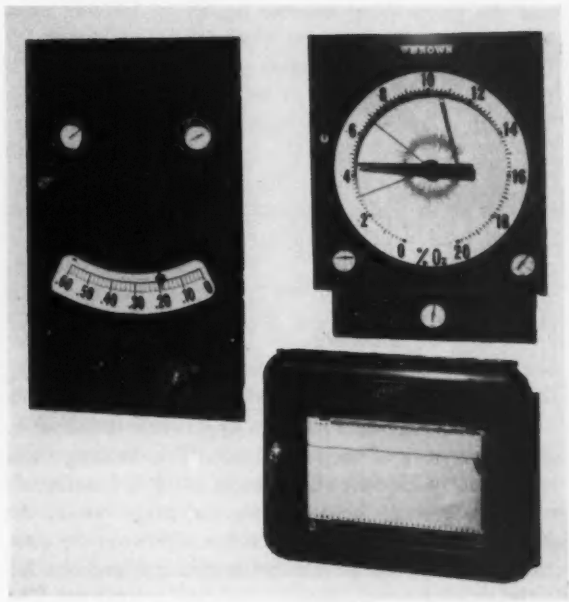


Fig. 8b Automatic control—small fluctuations



PART 2

If satisfactory e.r.s.-gauge bridges are given, mechanical design assumes paramount importance

Load cells in industrial weighing

by **R. B. SIMS, B.SC., PH.D., M.I.MECH.E., A.INST.P.**
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Introducing the subject last month, we narrowed down the discussion to the e.r.s.-gauge type of load cell. Having formulated their general equations, we went on to consider the accuracy of such load cells, and began an analysis of the errors due to e.r.s. gauges. At the end of Part 1 we were considering the effects of electrical overloading.

If the maximum safe current of the load cell is exceeded, its output at zero load (Z) becomes unstable and the random changes in Z increase rapidly if the current is increased. This zero drift is due to the fact that each gauge of the bridge has a different capacity for heat dissipation. After the rated maximum current is exceeded, the thermal stability of the bridge is upset and the gauge wires become heated at differing rates. The effect is discussed by McFarland and Dimeff (*8*). In very highly accurate systems similar to that shown in Fig. 25 which indicates to an accuracy of $\pm$ 10 lb in 30,000 lb a curious phenomenon can be seen when the load cell is loaded and unloaded. On sudden unloading (i.e. in a test machine during calibration) the indicator shows a small positive displacement proportional to the applied load which disappears after about 30 s. The maximum error is about + 15 lb, and careful checking shows that it is caused by heating of the measuring element due to the release of elastic energy as the load is removed.

Operation above rated temperature

Most manufacturers place an upper limit to the working temperature of their load cells. This limiting value is decided by the drift which occurs owing to interference with the heat dissipation from the gauge wires; the reduction in the strength of the bond between the e.r.s. gauges and the elastic measuring element, and the fall in the insulation resistance to earth in the load cell. The first of these limiting factors has been discussed above; the second is a function of the adhesive used. If a nitrocellulose adhesive is employed, creep at maximum load is appreciable above about 27°C, and this temperature cannot be exceeded in load cells in which it is used without the risk of substantial zero drift. Where thermosetting resins are used, such as Araldite 15, a working temperature of 45° is permissible, but not advisable unless the ambient temperature is kept uniform. At high ambient temperatures, large rapid fluctuations frequently occur in practice, giving rise to non-uniform heating in the load cell, and, as discussed above, these are reflected in variations in the zero. The third factor, the loss of insulation with temperature, is important and rarely appreciated. At temperatures over 60°C the insulating properties of most adhesives are impaired. The insulation of the e.r.s. gauges from the elastic measuring element is provided by the adhesive, and should be maintained above 100M Ω. If a load cell is heated it will be found that the insulation falls rapidly with temperature (*9*) until at 100°C it is less than 10 MΩ. Provided that the load cell has not been overloaded at those high temperatures, it will return to its original zero output and high resistance to earth when it cools to room temperature, and is unloaded. The properties of two adhesives are listed below, the results being obtained from one gauge bonded to a steel test strip.

TABLE 1

TEMPERATURE °C	ARALDITE 15 INSULATION MΩ	NITRO-CELLULOSE CEMENT INSULATION MΩ
60	>1000	>1000
70	700	600
80	350	200
90	250	70
95	200	50

Main mechanical troubles

Referring again to Fig. 4, the main sources of mechanical troubles in e.r.s. gauges are in the interwire separation, and the spot welds. The area occupied by the gauge wire must be kept fairly small, whilst the gauge resistance should be about 200 Ω minimum if a reasonable current is to be carried. Thus with wire 0·001 in. dia. (0·025 mm) the gauge area is usually 0·125 in. × 0·5 in. (3 × 12·5 mm) and the separation is about 0·015 in. (0·375 mm). The stresses at the bonds in the wire at each end of the 'gridiron' pattern are considerable. If the separation is decreased the wires may touch, or the insulation between them break down at elevated temperatures, and creep may occur as the ends pull away under heavy strain. The gauge may vary intermittently in resistance on a short-time basis if the spot welds are not made properly, and failure at this point is not uncommon in inferior gauges. The reason for the conventional use of wire 0·001 in. dia. is not known, and most e.r.s. gauges would be better for the use of thicker wire.

It cannot be emphasized too strongly that the most rigorous control must be exercised in all the stages of e.r.s. gauge manufacture and application. Such inspection is costly; experienced personnel must be employed, and rejects must be expected; some of them after the manufacture of the load cell is well advanced or even complete. This naturally makes the load cells more expensive than might be anticipated at first sight; but the reliability of the delivered product should more than amply compensate both manufacturer and user.

ERRORS DUE TO LOAD-CELL DESIGN AND APPLICATION

Once the technique of forming a successful e.r.s. gauge bridge has been acquired, the mechanical design of the load cell and its installation becomes of paramount importance. Errors due to faulty design may occur, and the following points must be watched:

1. The load-cell design must ensure that the output is linear with load.

2. Under industrial conditions unsymmetrical loading must be expected and the design should be arranged to accept all possible distributions of load with the minimum of error.

3. Side thrusts cannot be avoided in practice and the load cell should be designed accordingly.

4. Where excessive side thrusts (such as wind loads on structures) are unavoidable, an adequate system of tie rods must be provided which does not affect the measuring accuracy of the system.

5. Load cells must be designed with maximum thermal capacity to shield the e.r.s. gauges from non-uniform heating. Alternatively, water cooling must be provided. In accurate systems allowance must be made for the effect of temperature on the elastic modulus of the material from which the elastic measuring element is machined.

6. E.r.s. gauges must be proofed against ingress of water which will quickly put the load cell out of action.

7. Tanks and similar structures must be supported kinematically so that elastic and thermal distortions can occur in them without damaging the load cells.

Proportionality between output and load

Given good mechanical design and the correct choice of gauge wire (see **1.** under *Errors due to e.r.s. gauges* above) no load cell should have a non-linear relationship between load and output. It is impossible to draw up a set of rules for load cell design. The non-linearities which exist in a completed cell are due almost always to errors in detailed stress analysis and not to major design faults. Frequently they are discovered only when a new design has reached the prototype stage, and then only after detailed testing. An early proving-ring type of load cell is an example of non-linearity due to faulty mechanical design (Fig. 6). In order to achieve economy in manufacture the load was applied to the forged steel proving ring through two anvils dowelled to its neutral axis, whilst the e.r.s.

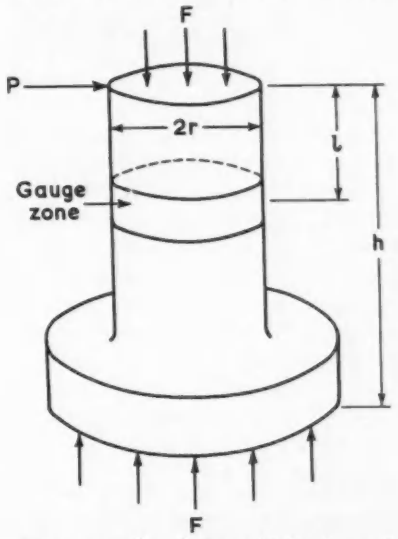

Fig. 8 Column-type load-cell, shown schematically

gauges were bonded on the horizontal diameter. It was found to be about 0·2% non-linear, and the zero was not completely stable owing to small and irregular changes in the attitudes between the anvils and the ring which varied the strain distribution in the region of the gauges. Therefore the load cell no longer conformed to Hooke's law, which is fundamental to all successful designs. It was eventually abandoned, since the truly linear solution involved machining the ring and anvils integrally, and required elaborate precautions to ensure uniform axial loading. It was, therefore, an uneconomical design when compared to the alternative methods available for measuring small loads.

A linear load-cell is essential when attempting very high accuracies. The accuracies achieved with properly designed cells using a standard self-balancing potentiometric indicator, is ± 0·3% of full load, at any load, and nearly all the error comes from the indicator. In an installation designed to measure 100 tons, therefore, the accuracy would be ± 300 kg at any point of the

scale. For many applications such accuracy is inadequate, and scale expansion must be used; a technique discussed in detail below. Accuracies of better than $\pm 0{\cdot}05\%$ of full load, at any load, may then be achieved by offsetting part of the output against a network of precision resistors, and measuring only a small part of the load on the potentiometric indicator. If, in the above example, a load of 100 tons is to be measured to high accuracy, the scale would be divided into five ranges of twenty tons, and the indicator scaled 0–22 tons, reading to an accuracy of $\pm$ 0·3% of the span or $\pm$ 66 kg. When a load of 86 tons is to be weighed, the load-dividing switch is set to eighty tons. This backs off the load-cell output against a precise potential equivalent to eighty tons, and the remaining six tons is then displayed on the indicator to an accuracy of better than $\pm$ 66 kg, i.e. to an overall accuracy of $\pm 0{\cdot}06\%$ of the 100-ton span. Accuracies of this order can be achieved with relatively simple circuitry only if the load cells are strictly linear, since the sensitivity of the potentiometric indicator is fixed and must be equivalent to a load of 22·0 tons whether the load is in the range 0–22 tons or 80–102·0 tons. It is true, of course, that non-linear measuring circuitry can be devised to correct for non-linearities in the load cells, but the complexity is then formidable, the equipment costly and difficult to check and service, and the load cells are not interchangeable. As an example of the linearity of modern load cells, the installation shown in Fig. 7a and 7b may be quoted. The hydrofluoric acid storage tank mounted on four load cells has an all-up weight of eighty tons, and a capacity of 50 tons of liquid. The scale is graduated 0-50 tons and 0-5 tons, so that up to five tons of acid can be dispersed to an accuracy of $\pm 0{\cdot}03\%$ of full load, at any load. The load cells are interchangeable and the circuit is simple enough to be serviced on a routine basis.

Distribution of load

The problems associated with load measurement when the loads are distributed non-uniformly on a load cell are considerable. The commonest design of load cell is shown in Fig. 8, and will be referred to here as the column type. In deriving equation 5 the assumption was made that the strain at the gauges, $\varepsilon = F/\pi r^2 E$, but this is true only if the load is uniformly distributed over the e.r.s. gauge zone.

St. Venant's principle states that a stress distribution can only be considered constant over a uniform section of a body when the section is more than about six diameters away from the point of application of load. This would imply that, for accurate measurement, the gauge area in the column-type load-cell in Fig. 8 must be a distance greater than $12r$ from the top of the load cell, and since a uniform distribution cannot be guaranteed over the base of the cell, the total height h of the instrument would need to be of the order of $24r$.

It has been shown experimentally, however, by Sims, Place and Morley (*4*), and theoretically by Bishop (*10*), that the stress distribution over the gauge area is reasonably uniform when the ratio $h/2r \geqslant 1{\cdot}15$. The specialized loadmeters built by the author's company for rolling mill applications are designed around this criterion, but research has shown that accurate measurements are not possible with a simple four-gauge bridge as shown in Fig. 1. Instead the eight-gauge bridge shown in Fig. 9 is used, and this gives a closer integration of strain over the elastic measuring element. Nonetheless, in designs using a criterion of $h/2r \simeq 1{\cdot}2$ it is not possible to achieve absolute accuracies closer than $\pm$ 2% with non-uniform loads with the simple eight-gauge network; the greatest errors occurring when the load is concentrated on a small area in the centre of the measuring column, and this, unfortunately is the most usual load distribution met in practice. Attempts have been made from time to time to improve accuracy on these short-column load-cells by using more sophisticated gauge arrangements, but without great success. On the other hand, with a load distributed uniformly over the

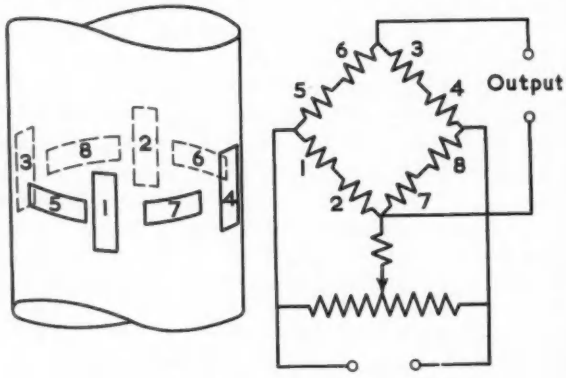

Fig. 9 Eight-gauge load-cell bridge and circuit

surfaces of the loadmeter, with an eight-gauge network, and with an $h/2r$ ratio $\geqslant 1{\cdot}15$, the linearity will be closer than $\pm 0{\cdot}07\%$ of maximum rated output, at any load.

If measuring accuracies of the order of $\pm 0{\cdot}1\%$ or better are to be attempted under *any* load distribution, it is essential that $h/2r \geqslant 3$ and this requirement introduces special problems into the design of column-type load-cells designed for rated maxima of less than about 100 tons. The design problems occur when a cell is subjected to side thrust. In practical systems it is almost impossible to avoid some side thrust, even when tie rods are fitted to the structure to absorb it, since the compliances of such devices are large. Moreover they add to the overall cost of the installation. The simplest method of applying load cells to a structure, therefore, is to bolt them to a firm foundation and anchor the structure to them in a kinematic fashion, allowing the structure to move freely with load and temperature changes, but restraining it from any other movement in the horizontal plane. Such a method of support must clearly impose considerable side loads on the load cells.

To be continued

PART 2

Pressure differences down to ±0·005 inches of mercury are recorded without difficulty in a system that can handle 288 pressures in 61¼ seconds

Digital recording in multipoint pressure surveys

by **M. B. WOOD**
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and **J. N. W. BALDWIN**
Aircraft Research Association Ltd.

In Part 1 (page 110 last month) we explained the need for a fast and accurate method of recording pressure distributions on models tested in wind tunnels, and opened an account of the system used at the A.R.A. First we described a pressure transfer valve which makes it possible to connect one transducer to each of 48 inlets in turn, and then we provided details of the pressure transducer and measuring system. Finally, we gave a description of the shaft digitizer* and relay store.*

OPERATION OUTLINE

In order to use the maximum punching rate of the Creed machine, the control of the six Scanivalves is divided into three separate channels which are dealt with sequentially. Thus during each recording cycle, three pairs of Scanivalves are stepped individually, while the Speedomax recorders are interrogated at the same times, allowing the reperforator, always two operations behind each channel (Fig. 7), to punch continuously. The use of fewer than six channels does not affect recording time since the tape format must be adhered to rigidly for computing.

A signal can be supplied automatically by each Speedomax, indicating that a balance has not yet been reached. This signal is arranged to inhibit digital interrogation and punching until the Speedomax servo-motor ceases to hunt. Oscillatory pressures, which are not uncommon with certain model shapes, are liable to prevent the recorders from balancing within the normal time. For this reason provision has been made for the overriding of the off-balance signal. Operation of this facility is recorded by a side pen drawing on the Speedomax chart. It is hoped to develop some means for discrimination between small oscillations and a genuine lack of balance in the near future; this will obviate the necessity for manual overriding.

In order to avoid wastage of tape and time in both computation and tunnel running, facilities have been provided to preset the number of pressure points to be recorded from each Scanivalve up to the maximum of 48 provided. This number of points ($2n$) is punched on the tape for computation and record purposes.

For the majority of tunnel tests it is necessary to record aerodynamic forces and moments (on cards (*10*)), as well as pressure distribution. In these cases it is desirable that both recording systems should be

*As most readers probably guessed, there was an unfortunate interchange of blocks and captions in Part 1. The self-balancing recorder shown in Fig. 4 is actually the Speedomax, while the components in Fig. 5 are parts of the digitizer. We apologize for this inadvertent transposition.—EDITOR.

under the control of one person. To this end, a remote control facility has been incorporated in the force read-out console, with monitor lights indicating when the unit is ready, and the presence of a fault. The Creed reperforator has been modified to ring a bell when there is sufficient tape in its magazine for six further full scans. Despite this, it is considered desirable that an operator should be present to watch the more comprehensive monitor lighting system on the rack itself and check that the chart readings, while sufficiently large to permit of accurate recording, do not exceed the size of the scale.

The use of a repeater link to drive the recorder charts is dictated by the requirements of other departments using the instrument. The transmitter, which is located in an auxiliary unit, operates on 24 V d.c. and is driven through a gear train by a small reversible shunt motor to give a chart speed of approximately 10 in./min. These chart drives can be switched to operate forward automatically during each recording cycle, or at any time to be driven forward or in reverse from the same switch.

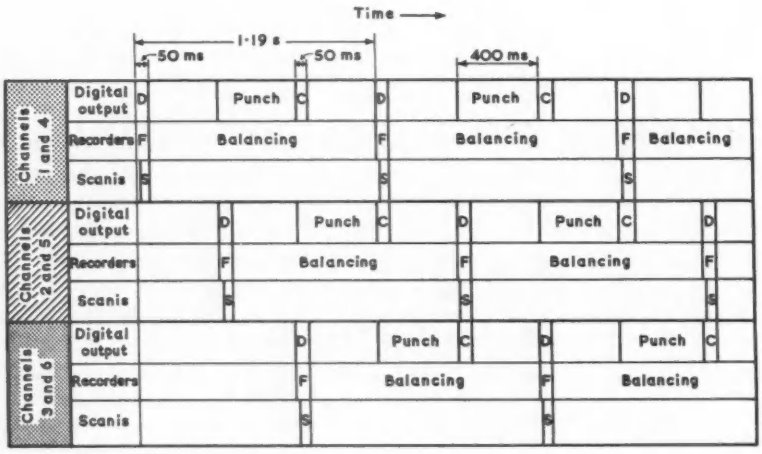


Fig. 7 Timing chart

TAPE LAYOUT (Fig. 8)

Reference information

Since the tape format produced by the recorder must fit into the existing record system used for computation, reference numbers indicating the model configuration, test number and scan number are punched in binary coded decimal form at the beginning of the tape. Also punched in the same way are the number of the pressures recorded ($2n$) and up to six further decimal digits; one at the start of the tape record and two groups, of four and one, at the end. These additional digits may be used for any extra information required, or suppressed altogether.

It will be noticed that all binary data are divided into blocks of seven 5-bit characters; thus allowing 35 bits per block. These blocks are built up into 35-bit words in the Zebra computer which uses the first and last bits for programming purposes. Each word so formed may then be placed in its appropriate address in the computer's magnetic store.

The words are further broken down, according to type, later in the programme.

Computer instructions

Immediately after the decimal information at the start of the scan, space is provided for one 35-bit store instruction needed for the computer's programme; this is wired in semi-permanently as it is expected to require changing only infrequently. A similar instruction is wired to be punched at the end of the scan, followed by seven blank characters also for computational purposes.

Auxiliary data

For calibration and records, facilities have been provided for the inclusion of up to six eleven-bit binary words to be punched at the start of each scan immediately after the first store instruction. This data is automatically repeated after the last pressure reading and can thus indicate any changes in the parameters it represents since the start of scan. The data usually recorded in this manner are the two tunnel speed pressures from the digitized beam manometers and a selection of such information as model incidence and roll angles, tunnel temperature, model base pressure and Mach number. These digitized readings are stored in binary code on relays in a specially developed decoder store (*3*), which can supply information to either the automatic pressure recorder or the force read-out system (*10*). Interlocks are provided to prevent both systems from interrogating the decoders at once. This type of decoder/store requires 300 ms to take its reading, but is only called upon to operate at a moment during the scan when it will not waste any time.

Pressure data

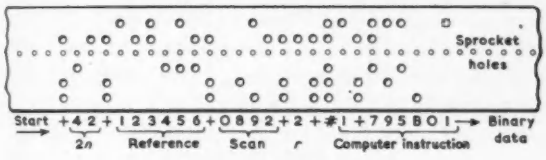
Each of up to six type-H Speedomaxes has a shaft-position digitizer mounted on its slide-wire wiper shaft.

The interrogation pulse for each pair of decoders also operates a relay on both Speedomaxes which removes the supply to the reference winding of the two-phase servo-motor, thus momentarily freezing the slide-wire position while the digital reading is converted to pure binary and stored. The stored eleven-bit binary number now appears on the scanning uniselector as shown in Fig. 8 in such a manner that ones are represented by a voltage of 110 d.c. and noughts by an absence of such potential. The sensitivity (*S*) or range in use on the Speedomax is also stored in the decoder and punched in the position indicated, in binary except for range 4 (20 mV f.s.d.) which is represented by the binary number 110. It will be seen from the diagram, Fig. 8, that each pair of digitized readings and sensitivity markers is contained within a seven-row group of 35 digits separated by one five-hole blank character. This will allow for the insertion of one single-character marker per pair of readings for any purpose.

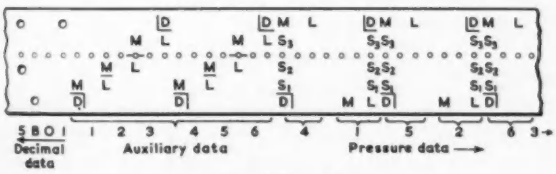
MONITOR AND CONTROL FACILITIES

Control unit

The single 5½-ft rack containing the equipment (Fig. 9) has at its centre, a panel fronting the scanning components and supporting the Scanivalve controls and indicator lights. For local control a 'start' button is provided and an adjacent three-colour signal lamp indicates that the unit is ready locally (blue), ready and control given to remote operator (green) or that the force-read-out system is in operation (amber). Each of the three Scanivalve control channels is provided with a three-position centre-off toggle switch for either manual stepping or homing its two Scanivalves. A three-colour signal lamp indicates that the Scanivalve(s) are home



A typical initial decimal record



Binary data layout

Fig. 8 Tape layout

(green), stepping (blue) or that they have become out of step with the system (red); in this latter case further scanning is temporarily inhibited until the Scanivalve is brought into step manually.

Parameter switchboard

This unit is situated immediately above the control unit and controls punching of the six decimal digits mentioned previously. Above the right-hand rotary switch is a small push-button which is operated to indicate that the switch beneath it has been set correctly. Operation of this switch also gives a ready signal to the remote operator and the number set will be punched in the initial decimal scan on starting the recorder. To the left are the switches for one four-digit and one

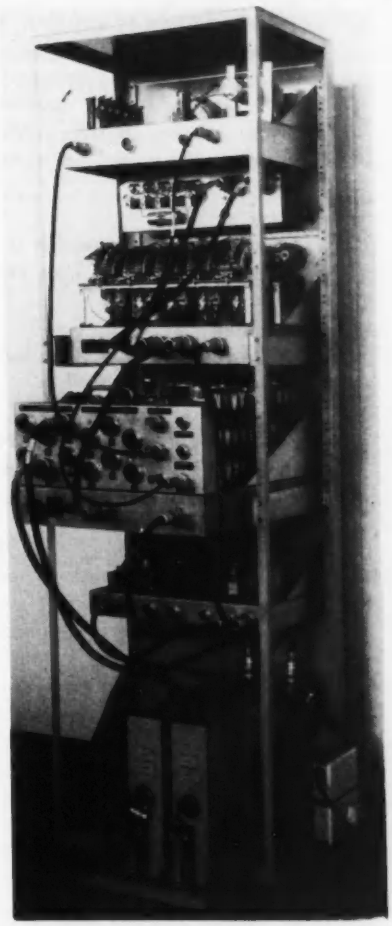


Fig. 9 Rear of control rack

single-digit number which are punched in the final decimal scan after binary recording is complete. This second additional data facility may be suppressed by the operation of a switch at the rear of the switchboard panel. When using this facility, the five switches involved must be set correctly before or during each scan, and the button above them pressed. Failure to press the button will cause a red lamp to flash regularly, and the final decimal recording will be inhibited until it is so pressed.

Counter unit

Sited immediately above the parameter switchboard is the unit which deals with all decimal punching. Two scanning uniselectors are provided; one to operate at the start of each record and a second one to complete the scan.

On the appearance of a start signal, the first scanner

operates and punches numbers in binary coded decimal, thus:

Four blank characters	*for computing*
Positive sign	*for computing (Zebra Input Code)*
2n	*Two-decimal-digit even number denoting the number of pressures to be recorded up a maximum of 48*
Positive sign	
Reference	*Six - decimal - digit number giving relevant model, configuration and tunnel run number*
Positive sign	
Scan	*Four-decimal-digit number increased by one each time the unit is operated*
Positive sign	
r	*Single-digit number switched from parameter board*
Positive sign	
#	*Cancel (five holes) sign indicating end of decimal information*
B	*Store instruction follows (Zebra Input Code)*

The reference number is set up by six manual switches wired to give a four-line binary output to each of six banks on the uniselector. The scan number is supplied by a three-decade uniselector counter giving a four-line output to each of three further banks on the scanning uniselector. Provision has been made for an extra decade to be added later if necessary. The succeeding scan number to be punched is monitored on a four-decade lamp display mounted on the front panel. It is possible to return this number to 0001, but this facility is not controlled on the panel for general use, as it was found desirable to retain continuity between sucessive runs with each model. After the second punching of the six auxiliary data words, the opening store instruction is inhibited, leaving seven blank characters, after which the second decimal uniselector is started. Wired into this is a further instruction followed by a positive sign, which indicates the end of binary data recording and prepares the computer for further decimal information.

For computation this is followed by seven blank characters and then:

Positive sign	
s	*four-digit decimal number*
Positive sign	
p	*single-digit decimal number*
Positive sign	
#	*cancel sign*

These last parameters are optional, and, as explained earlier, may be suppressed, giving a further sixteen blank characters following the last instruction. The next scan follows immediately.

POWER SUPPLIES

Six different potentials are used by the equipment: four of these, namely 110 V d.c., 115 V a.c., 50 and 24 V d.c., are supplied and switched by a power unit mounted on the digital rack; and the remaining two, 110 V a.c. and up to 12 V d.c. stabilized and regulated, for the Speedomax amplifiers and Statham transducers' exciting voltage respectively, mounted in each triple Speedomax cabinet.

Digital equipment power unit

A 500 VA mains transformer supplies a metal rectifying circuit followed by a 50 c/s smoothing filter for the punch solenoids circuit. The reperforator's motor is supplied by a type-A.100, 115 V transformer. Operation of the mains switch supplies current to both of the aforementioned transformers, and the coil of a K3000-type a.c. relay, the contacts of which interrupt the supply at 3 A from the main external 24 and 50 V d.c. power packs. Thus, all these potentials can be switched off by the mains switch in an emergency, but this is not desirable since a large inductive load could be broken by the low-voltage switching relay, causing damage to its contacts. Each supply, including the mains, has its own indicator lamp and switch; fuses at the appropriate rating are provided under each lamp.

Speedomax cabinet supplies

An individually screened supply at 110 V a.c. is provided for each Speedomax amplifier in its mounting cabinet. The three Statham transducers used by each cabinet are supplied from a Solartron transistorized power unit, type-AS 759.2, situated near and screened from the a.c. supplies. These Solartron units are each fully adjustable up to 12 V d.c. to allow for their possible use with other transducers: for Stathams they are adjusted to supply 4·5 V d.c.

With an output resistance of less than ·01 Ω and stabilization factor of 200: 1 the AS759.2 is eminently suitable for low-level d.c. work such as this. Noise and ripple is found to be well inside the manufacturers' limit of 1 mV peak-to-peak.

PERFORMANCE

Accuracy

Under normal tunnel running conditions it has been found that the equipment is capable of repeatability to ± 0·1% f.s. from day to day. In the light of experience, it is expected that better than ± 0·05% could be achieved without difficulty.

Recording time

From the foregoing it can be seen that the equipment functions in five phases. These distinct operations are tabulated (Table 1) together with the average times occupied by each.

From the table it can be seen that the total time *T* required for a complete recording using any number of

Scanivalves up to a maximum of six and allowing for no time wastage by oscillatory pressures or careless operating is given as:

$$T = R + D + A_1 + A_2 + 2nP + \frac{(C+S)(48-2n)}{48} \text{ seconds}$$

If all the Scanivalve positions are used, when $2n$ becomes 48, then $T = 61{\cdot}25$ s. Thus, if all six valves are used recording 48 points each (including 4 on each Scanivalve for calibration and marking purposes) 288 are recorded in each scan at a rate of approximately 310 points per minute. It will be seen from the graph (Fig. 10) that the constant recording time of decimal and auxiliary data causes the recording rate to rise with any increase in the number points used.

TABLE I *Operation times*

OPERATION	SYMBOL	PERFORMED BY	IN AVERAGE TIME OF	REMARKS
Reference punching	R	1 revolution of initial decimal U/S	1·21 s	
Auxiliary data recording	A_1	1 revolution of control unit U/S 3	1·03 s	Simultaneous operation of force read-out system could waste up to 300 ms
Pressure data recording	P	$2n$ revolutions of control unit U/S 2	$2n \times 1{\cdot}19$ s	This time could be greatly increased by the off-balance detector
Auxiliary data check recording	A_2	1 revolution of control unit U/S 3	0·65 s	A further time of 300 ms could be wasted by the force read-out system
Scanivalve homing	S	Relay GA	0·90 s for 48 points	
Counter homing	C	Up to 2 revolutions of control unit U/S 1	1·00 s for 48 points	
Final decimal parameter and store instruction punching	D	1 rev. of 2nd decimal U/S	1·24 s	Time could be lost here by the operator's failing to set up the parameter switchboard in time

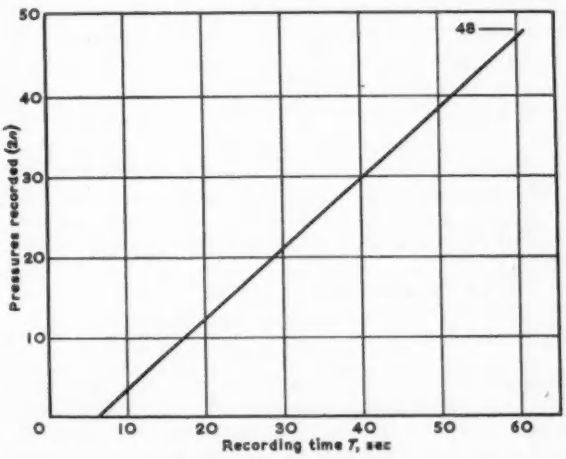


Fig. 10 Performance graph

In practice, wastage of time due to lack of balance at the recording instant ought not to require consideration as tunnel conditions should be steady before recording takes place; but it will be seen that any pressure which is continuously varying in an oscillatory manner within the response time of the pressure system and recorder will prevent continuity of punching. It would be possible to obtain a mean value for such a pressure by introducing lag into the pressure system by means of small reservoirs on each tube, but this is unsatisfactory because of space considerations and the fact that oscillatory pressures would not then be identifiable. As mentioned earlier, the off-balance detector can be over-ridden and the fact is automatically noted on the chart record.

CONCLUSIONS

The equipment described has been in use on the tunnel since May 1958, and has proved its own reliability in use in wind tunnel tests. From records of accuracy it has been found that pressure differences of down to $\pm 0{\cdot}005$ in. of mercury can be recorded without difficulty, and results will be as good as the pressure sealing of Scanivalves used and the truth of the pressure connexions to them will allow.

The only bar to a further increase in recording speed is the response time of the digitized chart recorders, as the space within models seldom permits the use of a full complement of Scanivalves. For this reason, a system based on the use of a digital voltmeter has been investigated and is currently being developed. It is expected to record the pressures at the Scanivalve at a rate of ten points per second on each channel to allow pressure surveys during necessarily short blow-down tests. The use of a single larger range will obviate range changing between tests.

Acknowledgments :

The authors wish to thank the Chief Executive of the Aircraft Research Association Ltd. for permission to publish this article. Grateful thanks are also due to Alan Tiffany, B.Sc., A.M.I.E.E., for advice and encouragement and to Miss Mair E. Coleman for her hard work at the typewriter.

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End

Concluding a review of practical design criteria

PART 2

Gearhead ratio selection in servo-motor drives

by **THOMAS B. WEARDEN, B.SC. TECH.**
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We begin Part 2 with a summary of the treatment given last month. In Appendix 1 we illustrate with examples how the alternatives of ratio > optimum and ratio < optimum should be considered when choosing a standard ratio, while in Appendix 2 we show how an expression for the correct ratio can be derived on the assumption that the motor-speed : torque characteristic is linear.

Summary

The criteria influencing the choice of gearhead ratio in servo-motor—load drive systems have been considered and the approach to practical design work suggested. Detailed explanation has been confined to the more simple cases where there is a clearly defined design objective and a predominant load torque component; however the arguments presented may be extended to cases with conflicting design objectives and two or more load torque components. As with all practical design the principles involved in the problem must first be clearly defined—and understood—and their relevance to the design problem then considered together with economic and other factors which may influence the final choice of gearhead ratio and gearing system.

APPENDIX 1

Example 1

A load with inertia 1000 g cm² and negligible frictional running torque is to be accelerated to an angular velocity of 300 rev/min, using a size-10, 2-phase a.c. servo-motor (Fig. 2) ($I_M = 0{\cdot}5$ g cm²). It is proposed to use a standard-ratio international frame size gearhead, for which a torque efficiency of 80% can be assumed. Acceleration should be as high as possible.

Using the principle of inertia matching, the gear ratio for maximum acceleration would be:

$$N = \left(\frac{1000}{0{\cdot}5} \times \frac{1}{0{\cdot}8}\right)^{\frac{1}{2}} :1$$

$$= 50:1$$

but with this ratio the maximum load speed would be approximately

$$\frac{\text{motor no-load speed (rev/min)}}{\text{gear ratio}} \text{ rev/min}$$

$$= \frac{6500}{50} \text{ rev/min}$$

$$= 130 \text{ rev/min}$$

so that the angular velocity requirement is not consistent with maximum acceleration.

(It is thus seen that, if a load speed is defined then maximum acceleration can be achieved only if the load inertia is adjusted.)

The gear ratio must therefore be defined as:

$$\frac{\text{motor speed when loaded by gearhead friction}}{\text{defined maximum load speed}}$$

If a size-10 or size-11 international frame size gearhead is used, manufacturers data shows the maximum running friction torque to be 0·75 g cm, and the load running friction torque is defined as negligible. Examination of the size-10 motor characteristics shows that motor speed will be reduced by approximately 100 rev/min by the application of a load of 0·75 g cm, and this may be regarded as negligible in the present case, so that the required gear ratio is then:

$$N = \frac{6500}{300} :1$$

$$\simeq 22:1$$

The nearest standard ratio with a size-10 gearhead is 20:1 so that actual maximum load speed is:

$$\frac{6500}{20} \text{ rev/min}$$

$$= 325 \text{ rev/min}$$

If a standard ratio of 25:·1 were employed the actual load speed would be 260 rev/min and in order to achieve the desired 300 rev/min the motor would have to be overrun, whereas if a 20:1 ratio is used the desired speed may be achieved by reducing the motor control phase voltage.

Example 2

A constant load of 8000 g cm is to be driven at 30 rev/min by a size-11 d.c. servo-motor. (Permanent magnet field, wound armature type.)

Power required to drive load:

$$W_L = 30 \times \frac{2\pi}{60} \times 8000 \times 10^{-4} \text{ watts}$$

$$= 2{\cdot}5 \text{ watts}$$

Power required from motor (assuming 80% gearhead torque efficiency):

$$W = 3{\cdot}15 \text{ watts}$$

From the motor characteristics (Fig. 3) it is seen that 3·15 watts of output power are available when:

motor torque = 40 g cm
motor speed = 7100 rev/min

Therefore optimum ratio is:

$$N = \frac{7100}{30} : 1$$

$$= 237 : 1$$

For this application a size-18 international frame size gearhead will be needed and the maximum running friction torque will be 0·75 g cm: this may be neglected when compared with the motor torque.

The nearest standard ratios available are 150:1 and 300:1. If 300:1 is selected, load torque referred to the gearhead input shaft is:

$$\frac{8000}{300} \times \frac{1}{0{\cdot}8} \text{ g cm}$$

$$= 33 \text{ g cm}$$

so that motor speed = 7600 rev/min (from motor characteristics)

and load speed = 25·3 rev/min

If 150:1 is selected, load torque referred to the gearhead input shaft is:

$$\frac{8000}{150} \times \frac{1}{0{\cdot}8} \text{ g cm}$$

$$= 66 \text{ g cm}$$

so that motor speed = 6800 rev/min

load speed = 45 rev/min

and the required load speed of 30 rev/min can be achieved by reducing the voltage applied to the motor.

APPENDIX 2

Theoretical calculation of gear ratio assuming a linear motor speed:torque characteristic, for design objectives constant defined load speed and maximum load speed: if a linear speed:torque characteristic is assumed for a servo-motor (Fig. 5) then the motor equation is:

$$\omega_M = \omega_{M(\text{no load})} - T_M \cdot \frac{\omega_{M(\text{no load})}}{T_{M(\text{stall})}} \text{ rads/s}$$

or

$$T_M = \frac{T_{M(\text{stall})}}{\omega_{M(\text{no load})}} (\omega_{M(\text{no load})} - \omega_M) \text{ g cm}$$

Power input to load is:

$$W_L = \eta \cdot \omega_M \cdot T_M \times 10^{-4} \text{ watts}$$

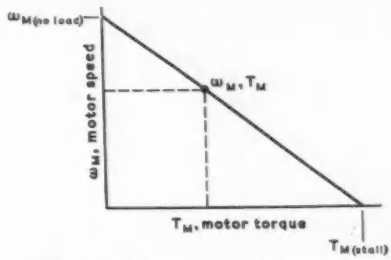

Fig. 5 Form of servo-motor speed : torque characteristic

$$= \eta \frac{T_{M(\text{stall})}}{\omega_{M(\text{no laod})}} (\omega_{M(\text{no load})} - \omega_M) \cdot \omega_M \times 10^{-4} \text{ watts}$$

If the load has one significant torque component, such that:

$$T_L = K_n \omega_L{}^n \text{ g cm}$$

$$W_L = K_n \omega_L{}^{n+1} \times 10^{-4} \text{ watts}$$

$$\therefore K_n \omega_L{}^{n+1} = \eta \cdot \frac{T_{M(\text{stall})}}{\omega_{M(\text{no load})}} \cdot (\omega_{M(\text{no load})} - N.\omega_L) \cdot N\omega_L$$

$$\therefore N^2.\omega_L - N.\omega_{M(\text{no load})} + \frac{K_n}{\eta} \cdot \frac{\omega_{M(\text{no load})}}{T_{M(\text{stall})}} \cdot \omega_L{}^n = 0$$

$$\therefore N = \frac{\omega_{M(\text{no load})} \pm \left(\omega_M{}^2{}_{(\text{no load})} - 4 \cdot \omega_L{}^{n+1} \cdot \frac{K_n}{\eta} \cdot \frac{\omega_{M(\text{no load})}}{T_{M(\text{stall})}} \right)^{\frac{1}{2}}}{2\omega_L}$$

and from this expression the optimum gear ratio may be calculated. (Gearhead running friction has been neglected in the above derivation. The method could be extended to include this parameter.)

From the parabolic shape of the motor power:torque (Figs. 2, 3) curve, it is seen that the peak motor power output is available when the above expression for gearhead ratio, N, has equal roots, i.e.

$$\omega_L{}^{n+1} = \frac{1}{4} \cdot \frac{\eta}{K_n} \cdot T_{M(\text{stall})} \cdot \omega_{M(\text{no load})}$$

and the maximum possible output speed is:

$$\omega_{L(\max)} = \left(\frac{1}{4} \cdot \frac{\eta}{K_n} \cdot T_{M(\text{stall})} \cdot \omega_{M(\text{no load})} \right)^{1/(n+1)} \text{ rad/s}$$

this being achieved when the gear ratio is:

$$N = \frac{\omega_{M(\text{no load})}}{2.\omega_{L(\max)}}$$

Useful results for special values of n are:

for $n = 0$, i.e. constant load torque

$$\omega_{L(\max)} = \frac{\eta}{4} \cdot \frac{T_{M(\text{stall})}}{T_L} \cdot \omega_{M(\text{no load})}$$

when $$N = \frac{2}{\eta} \cdot \frac{T_L}{T_{M(\text{stall})}}$$

for $n = 1$, i.e. viscous friction load,

$$\omega_{L(\max)} = \left(\frac{\eta}{4} \cdot \frac{T_{M(\text{stall})} \cdot \omega_{M(\text{no load})}}{K_n} \right)^{\frac{1}{2}}$$

when $$N = \left(\frac{\omega_{M(\text{no load})}}{T_{M(\text{stall})}} \cdot \frac{K_n}{\eta} \right)^{\frac{1}{2}}$$

End

Pick-off

by *'UNCONTROLLED'*

IN *News round-up* last month (page 136) there was a report of a visit to G.E.C. by an American trio of consultants. Called in by the Atomic Energy Division, these industrial psychologists have been advising on the 'human engineering' aspects of a tender for the C.E.G.B.'s nuclear power station at Sizewell. I was very interested to meet this team at a press conference in London recently, and was amused as well as instructed by a clash of courtesies in the opening remarks. Dr. K. J. Wootton, who manages the Atomic Energy Division, suggested that the American expression 'human engineering' is a better term for the study than 'ergonomics', which is used in some British circles. A little later, unconscious of any gaffe, the leader of the American team said that he and his colleagues were not engineers but 'behavioural scientists'! These three consultants have certainly brought fresh minds to bear, for as well as not being engineers they have not previously done any work on nuclear power stations. But Dr. Wootton was surely right in saying that their subject—whatever one calls it—has been much more intensively studied on the other side of the Atlantic than over here, and I for one was very impressed by what the team had to say. Much of it may strike one as common sense, after it has been said, but the astonishing thing about this kind of sense is its uncommonness.

As Dr. Ely, the leader of the team, pointed out, an intelligent man is a good decider but a poor monitor. Dr. Ely advocated relief of boredom by such methods as making a man's posture variable without affecting his lines of vision, moving men from department to department so that they can learn to take new responsibilities, and treating a tour of senior posts in a power station as one step to higher promotion in the C.E.G.B. He thought that a cathedral-like control room created the wrong impression in operators, and wanted a sense of intimacy for them—a sense that they were really the ones in control. He regarded the optimum number of men as three, one in charge and two assistants: or, as he put it, 'One brain with six hands.' Instrument panels should be arranged so that the human facility for pattern recognition is given full scope, and he demonstrated how the odd-man-out in a panel of instruments can be made much more evident if a suitable array is used.

The team suggests the use of a computer or simulator for three purposes: as an aid to the station physicist, as a device for training operators continuously to face emergencies of small or unknown probability, and as a predictor to help the operator in his choice of controlling action.

I was greatly taken by the modest delivery of the Americans, and by the way in which they acknowledged as new to them, and valuable, some of the ideas suggested from the floor. I am always refreshed by contact with open minds.

ACCORDING to last month's White Paper on defence (Cmnd. 952, 1s.), a Wellington bomber of the 1939–45 war needed 5 kW of electric supply for its ancillary equipment, while a present-day V-bomber needs 140 kW. The Matilda tank used a ¾-kW generator and this capacity has been quadrupled in the latest Centurion. The aircraft carrier H.M.S. *Hermes* can generate twice as much electric power as the carrier H.M.S. *Illustrious* did. *Hermes* uses about 9000 valves in its air defence system; *Illustrious* had less than 500. As the White Paper remarks, these increases give some measure of the last decade's development in radar, automatic control and fire power.

THE distinction between 'mechanization' and 'automation' is the first thing emphasized by expositors of the latter, though for my part I am beginning to be a little doubtful about it. I find it difficult to dispute with those who hold that automation is merely a particular case of the general principle of mechanization. Certainly the two seem to merge into each other at whatever boundary may be discerned between them. (No doubt I shall now be getting letters to tell me that the presence or absence of artificial feedback is the deciding factor!) Anyway, there is still a lot to be gained by straight mechanization. At a recent meeting of the S.I.T., Mr. T. A. Lucas of the S.E. Gas Board described—in a most engaging manner that many other lecturers could well copy—how conventional measuring and controlling equipment is used in the Segas cyclic plant. He pointed out that, where in 1949 there were 1050 works, now there are 463; yet the potential capacity has risen 20% and the labour force has dropped 25%. But, as Mr. Lucas recently told the Editor, mostly the improvement is due to the novelty of plant, with *some* help from new controls. (Readers who are interested will find the Segas plant described by Mr. Lucas on pp. 64–70 of last August's issue.)

I VISITED a large Midlands firm the other day and found a good example of an attitude that is, I fear, rather more common than many suspect. One of the processes at this firm's establishment consisted of cutting lengths of material to a certain accuracy. Originally this was a manual operation, and, as the process was run on a three-shift basis, the annual wastage was enormous. So a rather cunning little photocell system was devised, developed and installed, and the accuracy was improved more than fivefold. This was a great victory for the control engineer on the job, and he retired to his back room quietly to work out the annual saving that his brain-child would provide. But no saving of material was shown on the books, and, as far as the accountants were concerned, the expense of the control equipment had brought no benefit at all. When the astonished control engineer tackled the production people about this, they told him that they had *needed* the extra tolerance his equipment permitted. 'We've been fighting for years to get some leeway, and your gimmick has done the trick'. The control man could not refrain from the obvious retort, 'That's all very well, but you managed before'. Undoubtedly the use of automatic control in this case brought a gain somewhere, but the profit didn't show in the ledgers of those who made the investment.

Determination of transient response from frequency response

Graphical techniques for control systems—5

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METHOD 2: Derivation from closed loop Nyquist diagram.

Introduction

For this method the closed-loop frequency-response locus is required, either from calculated or test results. The transient response to a unit step-input is determined, the input step being considered as a constant input of unity with a superimposed repetitive pulse such that $f(t)=1$ for $T_0 > t > T_1$ and $f(t)=-1$ for $T_1 > t > T_2$ (Fig. 1).

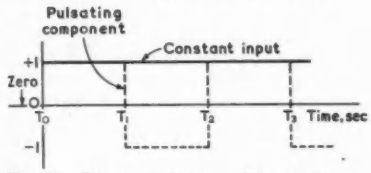

Fig. 1 Constant input with superimposed pulse

During time intervals T_1 to T_2, T_2 to T_3 etc., the function corresponds to a step input the amplitude of which is two units. Fourier analysis of the pulse gives

$$f(t) = \frac{4}{\pi} \sum_{1}^{\infty} \frac{\sin n\omega t}{n} \qquad \ldots(1)$$

where n is odd, and $\omega = 2\pi/T$, $1/T$ being the repetition frequency of the pulse. The transient response to a unit step-function will be half that of the continuous unit function combined with the pulse, providing ω values are selected so that the transient response is approximated to in time T_1.

Theory

The constant term has zero frequency and its contribution to the transient response is given by the zero frequency response vector R_0, illustrated for the particular case in which

$$\frac{\theta_o}{\theta_i} = \frac{1}{p^2 + p + 1} \qquad \ldots(2)$$

This locus is plotted in Fig. 2 as the frequency response locus, where $p \equiv j\omega$. Eq. 1 implies

$$f(t) = \frac{4}{\pi}\left[\sin\omega t + \frac{\sin 3\omega t}{2} + \frac{\sin 5\omega t}{5} + \ldots + \frac{\sin n\omega t}{n} \right] \ldots(3)$$

and this represents the pulsating part of the waveform: its effect on the output transient can be assessed term by term. This necessitates the location of an adequate range of odd ω values on the locus, and this requirement should be anticipated in test or calculated results. The first term of Eq. 3, i.e. $(4/\pi)(\sin\omega t)$ contributes a term to the output of the form

$$(\theta_o)_1 = (4/\pi)(R\sin(\omega t + \phi))$$

where $R \angle\phi$ is obtainable from the corresponding ω point on the locus, (vector $\overline{OA}$ Fig. 2). Expanding gives

$$(\theta_o)_1 = (4/\pi)[R\cos\phi\sin\omega t + R\sin\phi\cos\omega t] = (4/\pi)[a_1\sin\omega t + b_1\sin\omega t]$$

where a_1 is the real part of vector $\overline{OA}$ and b_1 the imaginary part. The nth term of Eq. 2 gives

$$(\theta_o)_n = \frac{4}{\pi}\left[a_n\frac{\sin n\omega t}{n} + b_n\frac{\sin n\omega t}{n} \right]$$

and the total output, including the constant term is

$$\theta_o = \tfrac{1}{2}\left[R_0 + \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{a_n\sin n\omega t}{n} + \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{b_n\sin\omega t}{n} \right] \ldots(4)$$

Summation of these terms by graphical assessment gives θ_o, but the procedure can be simplified, as

$$\frac{a_n\sin n\omega t}{n} \text{ and } \frac{b_n\cos n\omega t}{n}$$

are not independent. Considering negative values of time, for which the input is zero

$$(\theta_o)_{(-t)} = \left[R_0 + \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{a_n\sin(-n\omega t)}{n} + \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{b_n\cos(-n\omega t)}{n} \right] \ldots(5)$$

Substituting in Eq. 4 gives

$$\theta_o = \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{a_n\sin n\omega t}{n} \qquad \ldots(6)$$

Hence real components only need be considered.

Illustrative example

To illustrate the practical application of the method, a single value of the transient-response of Eq. 2 for a unit step-input is derived. Selecting 0·05 as the fundamental ω value and extending the analysis to the 31st harmonic gives, for evaluation for $\omega t = 15°$, the following figures which show the computational procedure.

(*See table at end*)

From this data, from summation of terms in the final row,

$$\frac{4}{\pi}\sum_{n=1}^{31}\frac{\sin(n15)°}{n} = 1{\cdot}05$$

This approximates to the transient response θ_o at a time value derived from the fundamental ω value of 0·05. Since $\omega t = 15° = \pi/12$ rad, $t = 5{\cdot}28$

DATA SHEET—16

seconds. In this example the transient response, by calculation, is

$$\theta_o = 1 - \exp(-t/2)\sin\left[\frac{\sqrt{3}}{2}t + \frac{\pi}{3}\right]$$

for unit step input. At $t = 5{\cdot}28$ seconds, $\theta_o = 1{\cdot}04$, demonstrating the validity of the graphical approach. For a step of magnitude θ_i the graphical result is $\theta_o = 1{\cdot}05\ \theta_i$. The above procedure is continued for 30°, 45°, etc. If the transient response is not adequately specified, a lower value of ω must be assigned and the procedure repeated.

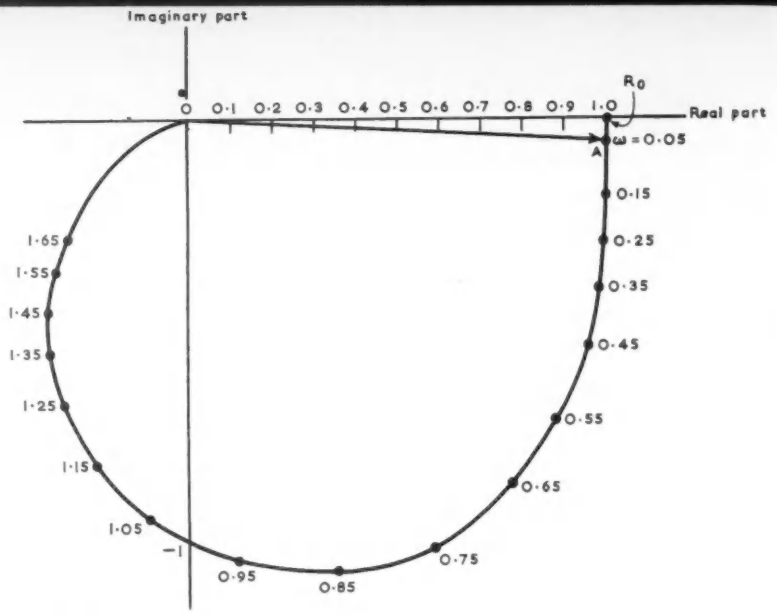

Fig. 2 (right) Frequency response locus for $p = j\omega$

TABLE I (*below*) *Computational procedure for values up to* n = 31

n	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
a_n	1·00	1·00	·99	·98	·96	·88	·77	·58	·36	·12	−·1	−·22	−·3	−·33	−·33	−·31
$\frac{a_n}{n}$	1·00	·333	·198	·14	·107	·08	·059	·39	·021	−·006	−·005	−·01	−·012	−·012	−·011	−·01
$\sin(15n)°$	·259	·707	·966	·966	·707	·259	−·259	−·707	−·966	−·707	−·707	−·259	·259	·707	·966	·966
$\frac{a_n}{n}\sin(15n)°$	·259	·234	·191	·135	·076	·021	−·015	−·028	−0·02	·004	·003	·003	−·003	−·008	−·011	0·01

LOOKING AHEAD

Unless otherwise indicated, all events take place in London. B.C.S. British Computer Society, Brit. I.R.E. British Institution of Radio Engineers, I.E.E. Institution of Electrical Engineers, R.Ae.S. Royal Aeronautical Society, S.I.T. Society of Instrument Technology, I.Mech.E. Institution of Mechanical Engineers.

TUESDAY 15 MARCH
Fast-Response Transistor Chopper-Type Amplifier with Low Carrier Frequency by I. C. Hutcheon and D. Summers. 5.30 p.m. I.E.E.

WEDNESDAY 16 MARCH
The Simulation of a Large Chemical Plant on an Electronic Analogue Computer by A. H. Doveton and K. C. W. Pedder. S.I.T.

MONDAY 21—TUESDAY 22 MARCH
Discussion on *The Computer in Production*. I.Mech.E.

TUESDAY 29 MARCH
Application of Transistors in Instrumentation by G. G. Bloodworth, S.I.T.

WEDNESDAY 30 MARCH
Silicon Photo-voltaic Cells for Instrumentation and Control Applications by V. Magee and A. A. Shepherd. 6.30 p.m. Brit.I.R.E.

TUESDAY 5—SATURDAY 9 APRIL
Ninth Electrical Engineers Exhibition. Earls Court.

THURSDAY 7 APRIL
The Electronic Computer as a Unit in an Automatic Electronic Data Processing System for Missile Trials by W. C. J. White and D. L. Overheu, S.I.T.

Novel Methods of Speed Control Applied to Standard Three-Phase Squirrel Cage Induction Motors by G. K. Creighton and W. M. Somerville. 5.30 p.m. I.E.E.

Preset Screwdown Control in Steel Rolling Mills by R. M. Epps. 5.30 p.m. I.E.E.

Linear Electrical Machines by P. J. Lawrenson. 5.30 p.m. I.E.E.

The Work of the B.S.I. in Relation to the Radio and Electronics Industry by H. A. R. Binney. 6.30 p.m. Brit.I.R.E.

FRIDAY 8 APRIL
Symposium on Data Handling and Display Systems for Air Traffic Control. 5.30 p.m. S.I.T. (All wishing to attend must register; forms available on application to S.I.T.)

MONDAY 11—FRIDAY 15 APRIL
Short Introductory Course on *Analogue Computing Techniques*. Loughborough College of Technology. Details: Dr. H. Buckingham, Loughborough.

WEDNESDAY 13 APRIL
Guided Weapon Control by F. R. J. Spearman. 6.30 p.m. Brit.I.R.E.

MONDAY 25—FRIDAY 29 APRIL
1st International Compressed Air & Hydraulics Exhibition and 2nd European Fluid Power Conference. London.

TUESDAY 26 APRIL
An Experimental Transistor-controlled Component Selection and Testing Machine by T. C. Cardwell, J. R. W. Smith and G. H. King. 5.30 p.m. I.E.E.
Control Section Annual General Meeting. 6.15 p.m. *Some Recent Advances in Industrial Electrical Control Techniques*. S.I.T.

TUESDAY 3 MAY
Discussion on *Teaching and Learning Machines*. Opened by C. E. G. Bailey. 5.30 p.m. I.E.E.

TUESDAY 3—FRIDAY 13 MAY
Mechanical Handling Exhibition and Convention, Earls Court.

WEDNESDAY 4 MAY
Computer Controlled Television Displays for Flight Simulators by J. N. Naish. 6.30 p.m. Brit.I.R.E.

FRIDAY 6 MAY
Discussion on *Methods of Recording Measurements—Digital or Analogue*. Opened by W. J. Perkins. 6 p.m. I.E.E.

WEDNESDAY 11 MAY
Radio Guidance in the Automatic Landing of Aircraft by J. Shayler. 6.30 p.m. Brit.I.R.E.

MONDAY 23—SATURDAY 28 MAY
Instruments, Electronics and Automation Exhibition, Olympia.

LOOKING FURTHER AHEAD

WEDNESDAY 15 JUNE—TUESDAY 5 JULY
7th Annual International Electronic, Nuclear and Cinematograph Exhibition, Rome.

FRIDAY 24 JUNE—FRIDAY 8 JULY
International Machine Tool Exhibition, London.

MONDAY 27 JUNE—WEDNESDAY 6 JULY
Moscow Congress for Automatic Control. Details: Hon. Sec. Group B, B.C.A.C., c/o I.E.E.

MONDAY 15—SATURDAY 20 AUGUST
11th Congress of the International Astronautical Federation. Stockholm.

WEDNESDAY 31 AUGUST—WEDNESDAY 7 SEPTEMBER
Annual meeting of the British Association for the Advancement of Science. Cardiff, S. Wales.

MONDAY 5—SUNDAY 11 SEPTEMBER
S.B.A.C. Flying Display and Exhibition. Farnborough.

TUESDAY 13—THURSDAY 15 SEPTEMBER
5th International Instruments and Measurements Conference and Exhibition. Stockholm.

WEDNESDAY 19—WEDNESDAY 26 OCTOBER
Interkama International Congress and Exhibition for Instrumentation and Automation. Düsseldorf.

Can machines do more of the work of the brain? Can they be taught to control industrial processes?

The ultimate basis of control

by **R. A. BROOKER, B.SC.(LOND.), M.A.(CANTAB.)**
Computing Machine Laboratory, Manchester University

ABOUT TEN YEARS AGO THE LATE ALAN TURING WROTE an article entitled 'Computing Machinery and Intelligence' (*Mind* Vol. LIX, No. 236, 1950) in which he considered the question 'Can machines think?' It is as stimulating to read now as it was then. In the course of examining various arguments to the contrary, including philosophical, mathematical, and physiological objections, he proposed that the main question be replaced by the following criterion. Let the machine (and he had in mind, of course, a digital computer) be matched against a human opponent in the 'imitation game', which is played as follows. By means of a teleprinter link, an interrogator in another room can ask each of them any question he chooses. The interrogator must try to determine from their replies which is the *person* (and the person endeavours to help the interrogator) and which the *machine*. If the machine could keep the interrogator guessing, even for five minutes, then (Turing suggests) we would have to admit that it could 'think'. To give some idea of the performance he had in mind, he suggested the following conversation piece:

Q. Please write me a sonnet on the subject of the Forth Bridge.
A. Count me out on this one. I never could write poetry.
Q. Add 34957 to 70764.
A. (Pause about thirty seconds and then give as answer) 105621.
Q. Do you play chess?
A. Yes.
Q. I have K at my K1, and no other pieces. You have only K at K6 and R at R1. It is your move. What do you play?
A. (After a pause of fifteen seconds) R–R8 mate.

It was Turing's belief that such a machine (with a storage capacity of at least 10^9 bits) would be realized within fifty years. Now that the Proceedings of the N.P.L. Symposium on the 'Mechanization of Thought Processes' have been published* it is interesting to see how near we are towards realizing this aim. Some progress has been made, but the machines available now have little more storage (10^5–10^6 bits) than the machines Turing was familiar with, and are only about a factor of ten faster. Machines under development (10^7 bits) will, I think, enable us to make a significant step forward, although we shall probably have to wait for a further round before we can seriously enter one as a player in the 'imitation game'. Turing was, of course, concerned with the purely intellectual aspects of thought processes. He made no suggestion that the machine be equipped with eyes, ears and a voice: but these are also associated with mental processes, and some of the contributions at the Symposium were concerned with speech perception and visual pattern recognition. The Conference, in fact, covered quite a range of activities, and was organized into five sessions: (1) General principles, (2) Automatic programming and language translation, (3) Speech recognition and learning in machines, (4a) Implications for biology, and (4b) Implications for industry, the last two being parallel sessions.

THE MAIN PROBLEM

Strictly speaking only two papers (in Session 1) are concerned with a general attack on the main problem. The first of these, 'Some Methods of Artificial Intelligence and Heuristic Programming' by Dr. Marvin Minsky, is concerned with the creative aspect of mental processes. Whereas we have rules for *deductive* reasoning, for *inductive* reasoning we have only suggestions; for example systematic searching, use of analogies and learning by generalization, use of sub-problems, etc. He develops the idea of building up within the machine a record of problem types and methods for solving them, listed perhaps in the order in which they are most

* *'The Mechanization of Thought Processes', published by H.M.S.O. for the D.S.I.R. in two volumes, price £2 10s. (U.S.A. $9).*

likely to succeed. Some of these notions are explained in connexion with a programme developed for handling some of the early theorems of Euclid. Thus at some stage in a search process the programme might need to show that two angles are equal, in which case it would refer to the problem method tables where, listed in order of priority, would be methods of which the goals are to show that the angles (1) are in congruent triangles, (2) are in similar triangles, (3) are alternate interior angles, etc. The author shows how such a programme would 'prove' that the base angles of an isosceles triangle are equal.

Although deductive reasoning is regarded as a fairly mechanical task, in fact no machine has yet been programmed to perform elementary verbal reasoning. John McCarthy's paper entitled 'Programmes with Common Sense' is concerned with just this problem. It describes a proposal for communicating with a computing machine in a combination of declarative and imperative sentences. This is in fact how one instructs a human computer: with declarative sentences describing a situation in which action is required, and with imperatives that say what is wanted. The intelligence, if any, will not be built into the programme, but embodied in the declarations. The programme will be called the 'advice taker'. One will be able to specify premises and the machine will draw conclusions Thus, for example, assume that I am seated at my desk at home and I wish to go to the airport. My car is at home also. The solution of the problem is to walk to the car and drive the car to the airport. However, even reasoning of this relatively simple order is quite a formidable task to simulate on a computer, and is less 'deductive' than would appear at first sight. To operate at any reasonably sophisticated level the machine would have to accumulate some hundreds of thousands of facts (in the form of 'advice'), and the decisive question of how it will pick out those facts which will serve as premises (in addition to those explicitly stated) is promised in another paper. Until this appears, however, one is forced to conclude that the author is only scratching the surface of the problem—which virtually amounts to teaching the machine to 'understand' English.

AUTOMATIC PROGRAMMING

In the next session we come to automatic programming. Here the machine is asked to help us in a very specialized domain of thinking, and in some respects a very appropriate one, namely preparation of its own computational programmes. The problem is to translate from the language in which the calculation is presented, mathematical symbolism, into commands which the machine can execute directly, i.e., the basic instruction code. The first paper (by Dr. Grace Hopper) is concerned mainly with business data processing. This is followed by an account of the Mercury Autocode programme, and the I.B.M. Fortran systems, 1 and 2. The Fortran translator runs to approximately 25,000 instructions representing about eighteen man-years of effort. It goes to great lengths (some would say unnecessary lengths) to rearrange the order of the calculation in order to produce an efficient target programme, for example, by eliminating common sub-expressions from algebraic formulas and optimizing the use of index registers. There is also an account of some Russian work in this field. This has proceeded on rather different lines from those followed in the west. One of the reasons for this, apparently, was the early lack of alpha-numeric input facilities, so that everything had to be encoded as a string of figures. However, it seems that there is no shortage of semi-skilled personnel to do this, so that programmers proper are free to use any notation they like, and are not restricted to the range of symbols found on a teleprinter keyboard, or to 'one-dimensional' line formulas. Thus workers in the field of automatic programming have been able to concentrate on strategical problems in which they have the active support of many theoretical workers in logic. (Programming research counts as 'respectable' mathematics in Moscow University.)

Typical of the problems they are thinking about is the following. Consider the series

$$u = \sum_{k=0}^{n} x^k/k!$$

If the terms are accumulated in the order shown, the general term would normally be evaluated by multiplying the preceding term by x/k—that is to say, a reasonably intelligent programmer would do it this way. This, and similar problems involving the substitution of recurrence relations for functions of an integer, could in principle be solved by the machine itself. If so, then the programmer has only to write down the general term in closed form and leave the machine to work out the details. Surely a manifestation of intelligence! Somebody will doubtless remark 'yes, but it hasn't done anything new, since you have told the machine how to do it'. This is perfectly true, but it must be pointed out that somebody has, at one time, also told the programmer how to do it, since he has doubtless been taught the 'step-by step' principle, namely, always, when advancing a step, try and make use of information at the previous step.

LANGUAGE

Two papers were presented on language translation, and there was also a very brief account of some Russian work in this field. Mr. Richens' paper ('Tigris and Euphrates') compares the semantic and syntactic analysis of sentences, and discusses several current ideas for machine translation, such as the Thesaurus method, and his own suggestions for a formal algebraic interlingua of 'naked ideas'. Dr. Brandwood's paper, by contrast, was concerned with a particular problem of German/English translation, that of converting masculine or feminine pronouns to neuter pronouns, and vice versa. To do this the antecedent of the pronoun must be identified, which apparently is not always a simple

matter. Since the grammar books have little to say on this subject, Dr. Brandwood examined various scientific texts, amounting to about 200,000 words, with a view to formulating some *ad hoc* rules for this purpose. These, when applied to a new text, gave the correct result in about 83% of the cases. He estimates that a more detailed investigation might result in 90% success. The human solution to this problem is, of course, to locate the antecedent by semantic congruence, and high-quality machine translation will certainly have to contain some semantic analytic procedures.

INDUSTRIAL IMPLICATIONS

In the session on 'learning' Dr. Andrew discusses how machines can be taught to control industrial processes. His paper is particularly interesting because it attempts to bridge the gap between the so-called self-organizing computers (of the conditional probability type) and the classical statistical approach to the problem. This latter method is to set up an algebraic model of the equations governing the system and determine the parameters by regression, i.e., by fitting the model to the past performance of the system. This model is then used to predict the behaviour of the process for the current control settings and for variations in these settings. The techniques of linear programming would be used to find the optimum control settings. Since these calculations have to be done in real time, a fast computer is essential for this kind of work. It may be of interest to record here that the same approach has been used in a more abstract connexion to determine the best strategy for a machine to follow in playing draughts ('Some studies in Machine Learning using the Game of Checkers' by A. L. Samuel, I.B.M. Journal of Research Development, Vol. 3, No. 3, July 1959).

Turning to other industrial implications, papers were presented on the use of machines for medical diagnosis, legal argument, and administration. Much of this material was pure speculation, and most of the proposals put forward would certainly not be feasible on existing machines or even on those under development. We may expect, however, that in all cases where the non-routine character of decision-making is due to incomplete knowledge of the facts of a situation, then computers may play a part: for example, by preparing an analysis of market prices, or by evaluating the consequences of following a certain economic policy. In other words, subjective judgements should as far as possible be replaced by objective judgements.

HABITUATION

I have selected above only those topics which seemed to me to bear directly or indirectly on the problem of programming Turing's hypothetical machine, the means for constructing which may soon be available. However, there are many other interesting papers in these Proceedings which cover self-organizing systems, speech perception, pattern recognition, and biological studies. Of these last the very beautiful explanation of habituation given by Dr. Ross Ashby deserves mention. In his most interesting paper, entitled 'The Mechanism of Habituation', Dr. Ashby presented a theorem concerning the response of a fairly wide class of systems exhibiting states of equilibrium to a repeated stimulus: that successive responses tend to become smaller. The theorem also shows that, if the system is particularly rich in states of equilibrium, then the responses fall off exponentially. By the same reasoning he also explains the phenomenon of de-habituation, in which a system habituated to a monotonous stimulus will, if given a new stimulus, change so that the original stimulus will evoke a new response, greater than those resulting at the end of habituation. The theorem is not restricted to neurophysiological systems: *any* system (physical, mechanical or even abstract), which satisfies the postulates of the theorem, will habituate. Another interesting paper was that by Dr. McCulloch, who showed how to make reliable neuron* circuits from unreliable elements. More particularly he showed that by using three neurons to do the job of one, neuron circuits can retain their logical properties, or nearly all of them, in spite of common shifts of threshold sufficient to alter the properties of the individual neurons. The work was said to be inspired by a midnight conversation with the late John von Neumann, who, aware of the fact that alcohol changes synaptic† thresholds, asked how it was that he could still drive his car after drinking a tumbler of whiskey.

PATTERN RECOGNITION

It is appropriate to mention the work being done on pattern recognition (for example of handwriting) and speech perception. This is essentially a statistical problem because the patterns are not unique. Thus many millions of slightly different sets of stimuli will represent the letter *A*. Similarly the acoustic equivalent of a particular phoneme‡ may lie in a fairly wide range of frequency duration and intensity. In both cases a final decision can only be made on the basis of its lingual context, for example a doctor's prescription can often be understood only by a dispenser. Such recognition problems are formidable and can only be attempted by extremely fast digital computers. However, a lot can be done by analogue equipment to process the visual or acoustic signals and reduce the number of decisions to be made at the contextual level. Computers themselves will probably be used to design the recognition circuits embodied in such equipment, which, when perfected, will provide computers with eyes and ears. (The task of providing it with a voice would be comparatively trivial.)

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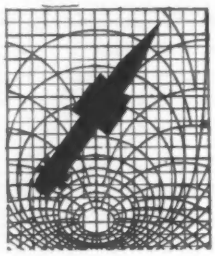
* *The* neuron *is the structural unit of the nervous system. It is a nerve cell with all its processes.*

† *The* synapse, *which is the association between nerve cells in higher animals, acts as a polarizer and selector. Its state at any instant determines whether a nervous impulse shall go through it to the next neuron.*

‡ *A* phoneme *is a group of variants of a spoken sound, usually spelt alike and taken to be the same sound, although varying a little with different neighbouring sounds.*



PART B

A general treatment of all currently used relays, motors and pilot-stage transducers

Hydraulic servos

by **P. D. BOYER, B.SC.**
English Electric Aviation Ltd.

Introducing the subject in Part A last month, we gave reasons for taking hydraulic g.w. servos to form a distinct branch of hydraulic control engineering. We considered where hydraulic systems are applied in missiles, and what are the demands made upon them. Having drawn attention to the reliance upon electrical signalling, we went on to state the basic properties of the hydraulic servos used. Finally we opened an account of components, pointing out that it may be inadequate to regard the amplifier as having an infinitely high frequency response. This is explained below.

Torque motors

Some typical torque motors are shown in Fig. 2. The torque motor is usually roughly linear in three variables, with the static characteristic

$$T_o = T_L = ki - C\phi$$

Dynamically the relation is

$$J\phi'' + b\phi' + C\phi + T_L = ki \qquad (1)$$

The stiffness C may be thought of as due solely to an inbuilt magnetic spring. Additional springs built into the torque motor, or acting upon it through the valve mechanism, form a static load

$$T_L = K\phi \qquad (2)$$

The static solution of equations 1 and 2 is evident in Fig. 3 as

$$\phi = ki/(K + C) = ki/K_1 \text{ say} \qquad (3)$$

The control valve itself may provide a very important part of the stiffness K in the form of a flow or jet reaction force and this too is discussed later. These static characteristics are used in steady-state design studies, for instance in the determination of maximum flow rate.

Frequency response of amplifier and torque motor with valve as load

In what follows, the significance of the inertia and damping values J and b is extended to include the referred inertia and damping of the valve treated as a load on the torque motor.

The amplifier is effectively a voltage generator driv-

continued on page 112

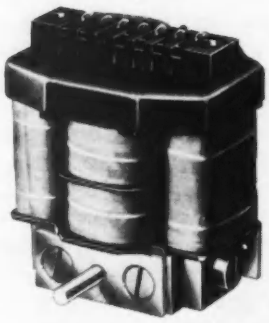


Fig. 2a Muirhead relay

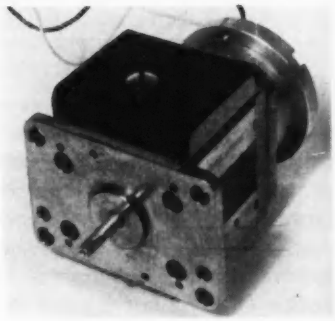


Fig. 2b Elliott W225/8B torque motor with position or velocity pick-off. Weight, 235 g

NOMENCLATURE

Note Derivatives with time are indicated in this article by primes. Thus $x' = \frac{dx}{dt}$, $x'' = \frac{d^2x}{dt^2}$, and so on

SYMBOL	FIRST OCCURS IN	SIGNIFICANCE
b	Eq. 1	Torque-motor damping coefficient
b	Eq. 15	Total damping coefficient referred to t.m. armature
f	Eq. 60	Operating frequency of servo
i		Torque-motor current (series value)
i		A small variation in i
j		$\sqrt{(-1)}$
k	Eq. 1	Torque-motor torque sensitivity $(\partial T/\partial i)_\phi$
k_1	Fig. 1	Pick-off gain
k		Slope of valve flow-displacement curve at constant pressure drop
l	Eq. 50	Displacement a of a hydraulic ram
p		Differential operator
p_m	Eq. 41	A small variation in P_m
q_m	Eq. 41	A small variation in Q_m
r	Eq. 11	Torque-motor effective crank radius
t		Time
v	Eq. 51	Volume of oil in pipe between valve and actuator (per cylinder)
w	Eq. 35	Total valve orifice width at any given port
x	Eq. 11	Valve spool displacement; displacement at working point of torque-motor driving crank
$\bar{x}$	Eq. 38	A small variation in x
y	Eq. 10	Torque-motor back e.m.f. per unit velocity
A		Ram area
B	Eq. 40	Damping coefficient of the hydraulic jack or actuator
C		Torque-motor internal magnetic stiffness
C_1	Eq. 40	Stiffness of any spring load on the hydraulic jack
C_d	Eq. 35	Discharge coefficient of valve metering orifice
C_{em}	Eq. 14	Equivalent parallel capacitance in torque-motor motional impedance
C_s	Eq. 30	Equivalent series capacitance in ditto
D_m	Eq. 41	Volumetric displacement of piston per unit linear or angular displacement of jack
E_s	Eq. 4	e.m.f. due to t.m. driving amplifier, open circuit
E_m	Eq. 4	Torque-motor back e.m.f.
F	Eq. 50	Force output of hydraulic ram
F_n		Some missile structural resonant frequency
$F(j\omega)$	Eq. 47	Servo-valve displacement-current transfer function
J	Eq. 1	Inertia of torque-motor armature
J		Total referred inertia on torque-motor shaft
K	Eq. 2	Stiffness of total effective spring load on torque-motor, i.e. excluding magnetic spring
$\bar{K}$	Eq. 41	Bulk modulus of elasticity of the oil
K_1	Eq. 3	Total stiffness of internal and effective external spring load on torque-motor
K_v	Eq. 64	Velocity per unit or Velocity Constant
L	Eq. 4	Electrical inductance of the t.m. with armature locked
L_{em}	Eq. 14	Equivalent parallel inductance in t.m. motional impedance
L_s	Eq. 30	Equivalent series inductance in t.m. motional impedance
M	Eq. 40	Inertia of the hydraulic jack and its load
N	Eq. 24	Some constant
P	Eq. 49	Pressure in a jack cylinder
P_A	Fig. 9	Cylinder pressure
P_B	Fig. 9	Cylinder pressure
P_e		Oil system exhaust pressure, often assumed zero
P_m	Eq. 44	Effective pressure drop across hydraulic jack. (Force/unit area is P-½P$_s$ in 3-way case)
P_s		Oil system supply pressure
$P_{1,2,3,4}$	Fig. 9	Pressure drops across metering orifices 1, 2, 3, 4
P_v		Valve orifice pressure drop ½[P_s–P_e–P_m] in 4-way case
P_c	Fig. 7 & p. 14	Value of P_v for which stiffness of spring is equivalent to flow reaction force = ½K_1
Q_m	Eq. 44	Output flow from servo-valve into actuator
R	Eq. 4	Combined resistance of amplifier output stage and the torque-motor coils (armature locked)
R	Eq. 50	Crank radius of rotary actuator
R_{em}	Eq. 14	Equivalent parallel resistance in t.m. motional impedance
R_s	Eq. 30	Equivalent series resistance in t.m. motional impedance
T	Eq. 23	Time constant of t.m. with armature locked, L/R
T	Eq. 50	Torque output of a hydraulic actuator
T	Fig. 12	Periodic time of servo input signal
$T(\theta, t)$		Torque output of actuator as a function of θ and t
T_c	Eq. 7	Torque on the t.m. rotor due to coils alone
T_L	Eq. 1	Load torque on the t.m.
T_o		Torque-motor output torque
T_1	Eq. 24	A time constant of the t.m.
T_2	Eq. 29	A time constant
V	Eq. 41	Volume of oil enclosed in an actuator cylinder
V_i	Fig. 1	Input signal voltage to servo
V_o	Fig. 1	Output signal voltage from servo
X		Constant coefficient
Y		Constant coefficient
Z_s	Eq. 14	Impedance of electrical analogue of Z_{em}
Z_{em}	Eq. 5	Additional equivalent series impedance of t.m. associated with armature motion
Z_m	Eq. 15	Mechanical impedance of t.m., force/unit velocity
α	Eq. 47	A constant
ϵ		Servo error θ_i–θ_o
ϵ_{ss}	Eq. 64	Steady state value of ϵ
ζ	Eq. 22	Mechanical damping ratio of t.m. $b/2(JK_1)^{1/2}$
ζ_1	Eq. 59	Damping ratio of hydraulic actuator
θ, θ_o, θ_i	Eq. 50	Displacement of a rotary actuator, output and input values
$\bar{\theta}$	Eq. 46	Amplitude of sinusoidal jack displacement
$\hat{\theta}_o$		Peak value of θ_o
θ'_{ss}	Eq. 64	Steady-state value of θ'
ξ	Eq. 24	Overal damping ratio of t.m.
ρ	Eq. 35	Oil density
σ	Eq. 37	Slope of the flow-pressure curve at constant valve displacement
ϕ	Eq. 1	Torque-motor angular displacement
ϕ	Eq. 60	Phase lag between θ_i and θ_o
ψ_o	Eq. 40	A small variation in θ_o
ω		Operating frequency (circular) of t.m.
ω_n	Eq. 22	Open circuit undamped natural circ. frequency of t.m. $(K_1/J)^{\frac{1}{2}}$
Ω_n	Eq. 24	Overall undamped natural circ. frequency of t.m.
Ω_n	Eq. 51	Undamped natural circ. frequency of a rotary actuator

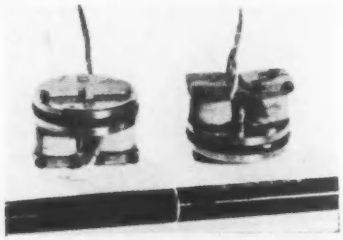


Fig. 2c Torque motor used in Sperry Spacemaster. Weight, 45 g

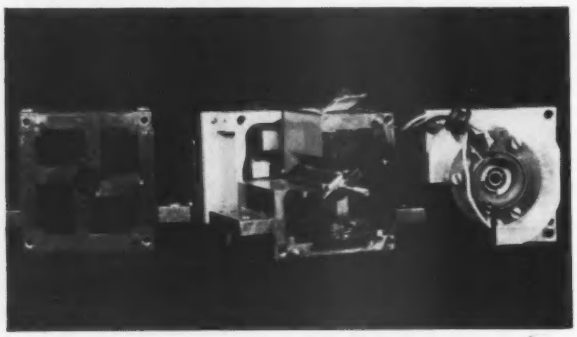


Fig. 2d English Electric torque motor used in Thunderbird. Photograph shows stator and sectioned assembly (end plate with potentiometer pick-off removed)

ing current through its own impedence and the series resistance and inductance of the torque motor. The torque motor is also a generator: it can in fact be used as a d.c. velocity pick-off. Thus the amplifier must drive the current against the back e.m.f. E_m generated by the torque motor. This back e.m.f. is solely dependent upon, and proportional to, armature velocity in a linear motor. We have

$$E_a - E_m = (R + pL)i \tag{4}$$

where R is the combined resistance of the amplifier output stage and the torque-motor coils and L is the electrical inductance of the torque motor, as it would be measured with the rotor locked. (Eddy-current losses require due allowance and are covered by checking the impedance at various frequencies in this condition.)

Now E_m may be considered as due to an additional equivalent series impedance, the motional impedance, Z_{em} so that

$$Z_{em} = E_m/i \tag{5}$$

and

$$E_a = (R + pL + Z_{em})i \tag{6}$$

Following an analysis due to Laws (*1*) we assume that a given current produces a given torque on the rotor in all circumstances and that the two are proportional. Thus the torque on the rotor due to the coils (but not to any additional permanent magnets) is

$$T_c = ki \tag{7}$$

It is convenient to use c.g.s. and absolute electromagnetic units in what follows. Assume that the back e.m.f. per unit velocity is

$$y = E_m/\phi' \tag{8}$$

Since the power converted from electrical to mechanical energy is $E_m i$ and the mechanical power transferred to the armature is $T_c\phi'$, then

$$T_c\phi' = E_m i \tag{9}$$

$$\therefore \quad y = k \tag{10}$$

$$\therefore \quad E_m = k\phi' = kx'/r \tag{11}$$

Two transfer functions are of primary interest, viz. x/i and x/E_a. These are found using equations 5 and 11, from which

$$x'/i = rE_m/ki = rZ_{em}/k \tag{12}$$

and

$$\frac{x}{E_a} = \frac{x'}{pE_a} = \frac{rE_m}{kpE_a} = \frac{r}{kp} \cdot \frac{Z_{em}}{(R + pL + Z_{em})}$$

or

$$\frac{x}{E_a} = \frac{r}{kp} \cdot \frac{1}{1 + \left[\dfrac{R + pL}{Z_{em}}\right]} \tag{13}$$

Laws has shown that Z_{em} is most conveniently represented by an analogue consisting of L_{em}, C_{em}, and R_{em} in parallel. The impedance of such a network is

$$Z_a = \frac{1}{\dfrac{1}{R_{em}} + j\omega C_{em} + \dfrac{1}{j\omega L_{em}}} \tag{14}$$

The mechanical impedance of the torque motor, by definition force/unit velocity, is

$$Z_m = \frac{T_c}{r^2\phi'} = \frac{1}{r^2}\left[j\omega J + b + \frac{K_1}{j\omega} \right] \tag{15}$$

from equations 1, 2, 3 and 7.

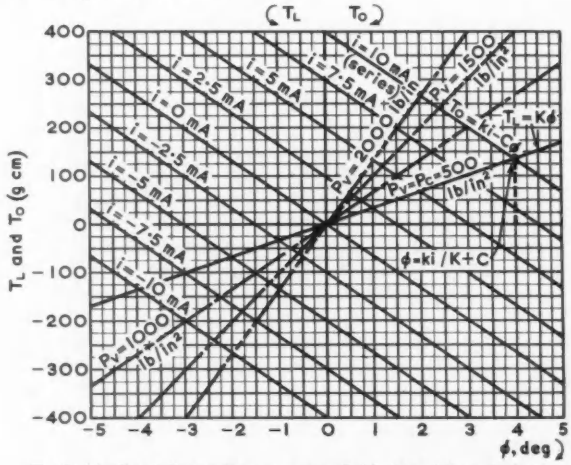


Fig. 3 Idealized linear torque-motor field plot with static-load lines for a simple spool valve (no external springs, no Bernoulli force reduction). Torque-motor stiffness, 66·6 g cm/°, i.e. C = 3·75 × 10^6 dyne cm/rad. Torque sensitivity, 40 g cm/mA (series), i.e. k = 39·2 × 10^3 dyne cm/mA. Valve port width w=1 cm. Discharge coefficient C_d=0·70. Torque-motor crank radius r=0·233 cm. Oil density ρ=0·85 g/cm³. Flow force = 2 ρ Qv cos 69° (see ref. 9) $\simeq$ xP_v = rϕP_v ∴ load torque due to flow force $T_L = r^2 P_v \phi = K\phi$. ∴ $\phi = (k/r^2)\, i/(P_v + C/r^2)$. $Q = C_d w r\phi (2P_v/\rho)^{\frac{1}{2}} = [C_d w (2/\rho)^{\frac{1}{2}} (k/r)]i\,(P_v)^{\frac{1}{2}}/(P_v + P_c)$.

Since

$$Z_{em} = E_m/i = k\phi'/(T_c/k) = k^2\phi'/T_c \tag{16}$$

then

$$Z_{em} = k^2/r^2 Z_m \tag{17}$$

$$\therefore \quad Z_{em} = k^2/(j\omega J + b + [K_1/j\omega]) \tag{18}$$

This eq. 18 makes Z_{em} calculable. Comparing eqs. 14 and 18 it is seen that the equivalent series-parallel inductance, capacitance and resistance are given by

$$L_{em} = k^2/K_1 \quad \text{(abhenries)} \tag{19}$$
$$C_{em} = J/k^2 \quad \text{(abfarads)} \tag{20}$$
$$R_{em} = k^2/b \quad \text{(abohms)} \tag{21}$$

Thus the individual components of the impedance do not conform to the conventional analogy between mass and inductance, compliance and capacitance, etc., but this does not prevent the analogue from being useful. However, it does mean that, for instance, L_{em} should not be quoted as the equivalent inductance of the torque motor.

The resultant transfer functions obtained using equations 12, 13 and 18 are

$$\frac{x}{i} = \frac{rk/J}{p^2 + 2\zeta\omega_n p + \omega^2{}_n} \tag{22}$$

$$\frac{x}{E_a} = \frac{\dfrac{rk}{RK_1}}{1 + \left[\dfrac{k^2}{RK_1} + T + \dfrac{b}{K_1}\right]p + \left[\dfrac{J}{K_1} + \dfrac{bT}{K_1}\right]p^2 + \dfrac{JT}{K_1}p^3} \tag{23}$$

Eq. 23 is difficult to simplify except by direct arithmetical methods, when it can be reduced to the form

$$\frac{x}{E_a} = \frac{N}{(1 + pT_1)(\Omega_n{}^2 + 2\xi\Omega_n p + p^2)} \tag{24}$$

Laws shows that, in certain instances, the response may be flattest and the damping ratio greatest (about 0·5) when $\Omega_n = 1/T_1$ but the condition for obtaining this is complicated, viz. that

$$JL(k^2 + LK_1 + bR)^3 = (JR + bL)^3 K_1 R \tag{25}$$

As a result

$$T_1 = 1/\Omega_n = (JT/K_1)^{\frac{1}{2}} \tag{26}$$

and

$$\xi = \frac{1}{2}\left[\left(\frac{J + bT}{K_1}\right)\left(\frac{K_1}{JT}\right)^{\frac{1}{2}} - 1\right] \quad * \tag{27}$$

Much more use in practice can be made of the transfer i/E_a. From eq. 6: —

$$\frac{i}{E_a} = \frac{1/R}{1 + pT + (Z_{em}/R)} \text{ or } \frac{1/R}{1 + \dfrac{Z_{em} + pL}{R}} \tag{28}$$

If R is made sufficiently large compared with Z_{em}, a condition obtained by using a pentode output stage, and/or possibly current feedback, then

$$\frac{i}{E_a} \simeq \frac{1/R}{1 + pT_2} \tag{29}$$

and T_2 itself becomes small.

To appreciate how large R should be made it is helpful to consider an alternative electrical analogy for Z_{em}, viz., a series inductance L_s, capacitance C_s and resistance R_s. This results in

$$R_s = \frac{bk^2\omega^2}{(K_1 - \omega^2 J)^2 + b^2\omega^2} \tag{30}$$

or

$$R_s = \frac{k^2}{J}\left[\frac{2\zeta\omega_n\omega^2}{(\omega^2{}_n - \omega^2)^2 + 4\zeta^2\omega_n{}^2\omega^2}\right] \tag{31}$$

* Rather than the value given by (*1*).

and

$$L_s - \frac{1}{\omega^2 C_s} = \frac{k^2(K_1 - J\omega^2)}{(K_1 - J\omega^2)^2 + \omega^2 b^2} \tag{32}$$

or

$$L_s - \frac{1}{\omega^2 C_s} = \frac{k^2}{J}\frac{\omega_n{}^2 - \omega^2}{(\omega_n{}^2 - \omega^2)^2 + 4\zeta^2\omega_n{}^2\omega^2} \tag{33}$$

It will be seen that as long as $\omega < \omega_n$, C_s can be treated as infinite, giving a series inductance and resistance, both variable with frequency. The r.h.s. of eq. 33 is then L_s. This was perhaps worth dealing with at some length since the very variable inductance values quoted for relays frequently cause confusion.

The effective inductance for $\omega < \omega_n$ is thus $(L + L_s)$ and eq. 28 becomes

$$\frac{i}{E_a} = \frac{1/R}{1 + \left[\dfrac{R_s + pL_s + pL}{R}\right]} = \frac{1/(R + R_s)}{1 + p\left[\dfrac{L + L_s}{R + R_s}\right]} \tag{34}$$

A typical Laws relay with:

Locked-armature inductance, $L = 0{\cdot}9$ henries ($0{\cdot}9 \times 10^9$ abhenries) at 1000 c/s

Stiffness $K_1 = 9 \times 10^6$ dyne cm/rad

Inertia $J = 5$ g cm²

Torque sensitivity $k = 9 \times 10^4$ dyne cm/mA (9×10^8 dyne cm/abamp)

Damping ratio $= 0{\cdot}1$

would have

Undamped natural frequency $\omega_n = 1340$ rad/s

and the following representative values for R_s and L_s:

At $\omega = 0$, $R_s = 0$

$\omega = 2\pi.100$, $R_s = 8660 \times 10^9$ abohms $= 8660$ ohms

At $\omega = 0$, $L_s = 90 \times 10^9$ abhenries $= 90$ henries

$\omega = 2\pi.100$, $L_s = 114 \times 10^9$ abhenries $= 114$ henries

An increase in k or reduction in K_1 will raise these values and much higher ones are possible. In order that the phase lag in i/E_a should be, for instance, $< 10°$ at 100 c/s, from eq. 34,

$$\tan^{-1}[\omega(L + L_s)/(R + R_s)] < 10°$$

and $\therefore \quad 114{\cdot}9/(8660 + R) < 0{\cdot}00028$

so that $R > 4 \times 10^5$ ohms

Thus it is necessary to make R much higher than can be obtained with a simple triode output stage.

Any measurement of the inductance in the locked condition may depend upon armature position if the torque motor is slightly non-linear, upon permanent-magnet magnetization or current levels if saturation is setting in, or upon frequency if the locking is not 100% effective in combating armature resilience.

With but little variation the treatment above should apply to all relays, motors and pilot-stage transducers currently in use.

To be continued

The achievement—and the danger—of Russian automation were well brought out in a discussion at the I.E.E. last month. Some of what was said is reported below

THE RED LIGHT

ATTENDANCE AT AN EVENING DISCUSSION on Soviet control-engineering progress was surprisingly less than heavy last month. Organized by the I.E.E. Measurement and Control Section for February 16, and well publicized among members of the B.C.A.C., it drew only a goodish audience. Professor Tustin took the Chair and introduced the panel of speakers who were to open the proceedings: the panel included members of the I.E.E.-British Council team that visited the U.S.S.R. last year (see CONTROL, December 1959, pp. 102–104).

Some first-hand observations

Launching the meeting with a reference to his own working stay in the Soviet Union, Professor Tustin commented on how significant for us was the existence of a society dedicated to the proposition that 'The advancement of science is a chief key to a better life'. Mr. R. E. Clark then described the place of science and technology in the U.S.S.R., drawing attention to the tendency for government to be in the hands of scientifically and technically trained persons. Much effort was being devoted to the development of translating machines, and although extravagant claims had been made in the Soviet press, there was still some way to go. Progress had nonetheless gone far enough for machines to be of some help to human translators. Russian effort in this field was huge compared with ours. There was heavy concentraton of work on theory—most of the product of this work was available outside the U.S.S.R. to anybody who wanted it—but there was some question as to how much of it had been translated into hardware. The Russians were assiduous readers and visitors, and they tended to see more of our doings than we saw of theirs. Mr. Clark concluded his remarks with a warning that any excess output from automatic factories in the Soviet Union might be dumped on 'our' markets.

While far from belittling the Russian achievement, Mr. R. H. Tizard (a member of the team that visited the U.S.S.R. last year) felt bound to mention that at the Moscow automatic ball-bearing factory there were no less than 10,000 workers employed! Only a part of the process was fully automated, and even that had one female operator stuck in the middle of it. There was a factory in this country, said Mr. Tizard, with almost identical machinery, but there were three girls instead of one (probably because the economics of the situation called for this multiplication). There was a tendency in the Soviet Union to automate for its own sake, rather than because there was any economic advantage in doing so. Mr. Tizard spoke of the widespread interest in digital techniques of instrumentation, data logging, and analogue-to-digital converters. Learning and self-optimizing systems were also popular subjects.

Mr. S. S. Carlisle (another member of the team) compared the Soviet approach to automation with ours. He thought that we might well follow the Russians in taking automation to be a desirable objective in itself. He referred to their logical approach to automation of furnace systems, starting with instruments and going on to automatic process controls with the ultimate aim of complete mechanization. Mr. Carlisle also thought well of the Russian idea of having small-batch instrument production units as part of automation research institutes, and he suggested that it be adopted in this country. He liked the method of running a simulator in parallel with a process, the parameters of the simulator being successively brought 'up to date' in comparison with those of the process; control signals could be obtained from the simulator that it was impossible to get from the process itself. One respect in which he thought that we might be ahead of the Soviets was in the handling of works information. He was careful to add, however, that the Russians might not be underrating the importance of this so much as not tolerating such an excessive diversity of product as we allowed ourselves in this country.

A third member of the team, Mr. A. Asbury (who wrote the article in our December issue), gave his observations on Russian applications of analogue and digital computers, instrumentation, and electric power (including traction).

Pre-eminent theorists

Mr. A. T. Fuller traced Russian interest in non-linear control theory back to 1892, and said that western mathematicians regarded the Russians as pre-eminent in non-linear work. Tsypkin's book on sampled-data systems was encylopædic and exhaustive, and his book on relay control systems was unequalled anywhere else in the world. The most important recent contribution from the Soviet Union was the mathematician Pontryagin's work on optimum saturating control systems. Mr. Fuller gave it as his opinion that the Russians were far ahead of us on the theoretical side.

How to get Russian information

Dr. D. J. Urquhart explained the arrangements existing in this country for the collection, translation and distribution of Soviet technical literature, and maintained that there were now as adequate facilities for getting literature from the U.S.S.R. as for getting it from other highly developed countries. The Lending Library Unit at the D.S.I.R., which had been operating for some time, had the largest collection of Russian scientific and technical literature in western Europe. Publications were available on loan to corporate bodies in the same way as they were available from the Science Museum Library. Unfortunately people were being rather slow in making use of the service. (Dr. Urquhart remarked in passing that the D.S.I.R. Unit was to move to York next year and become the National Lending Library for Scientific and Technical Literature.) He observed that Russian book production was a little bigger than that of the entire English-speaking world. This, he said, was because the Russians had discovered that people would write books if they were paid to do so. Books were commissioned and paid for on merit, not on sales. Much of the output of technical literature was not of new material, but it did put on record, and make generally accessible, information that was not so available in the west. He ended with a warning that, in the long run, Chinese interest should not be overlooked, but admitted that Chinese literature was hard to get at present.

PART 1

If a mathematical model is unsatisfactory, it is reasonable to construct a model of another kind

Analogue-computer analysis of rolling-mill controls

by **R. B. LARKINSON, B.A. (OXON)**
English Electric Co. Ltd.

THE METAL INDUSTRIES TO-DAY EMPLOY MANY SERVO-mechanisms for control, an employment forced on the industries in their search for increased production rates and higher quality of product. In a hot reversing mill, for example, the time taken in reversing the drive between passes is unproductive and must be kept to a minimum. Since there are large mechanical and electromagnetic inertias involved, forcing is necessary to reduce the effect of the various time constants. Thus high-gain feedback systems are required to obtain small reversal times. Similarly, in continuous mills the effect of impact drop as the metal enters the mill must be kept to a minimum so that the looping and stretching may be kept within small limits. High-gain speed controls are therefore used, and these will give a controlled regulation as small as ¼% to a system having an uncontrolled regulation of 16%.

The mathematical analysis of servo-mechanisms consists essentially of two stages.

STAGE 1. Calculation of the open-loop behaviour of the system—phase and magnitude of the output for sinusoidal inputs of constant amplitude but different frequencies.

STAGE 2. Calculation of the behaviour of the system with loop closed when non-sinusoidal functions such as steps, ramps etc. are applied at various points.

Stage 2 is a laborious process which involves finding the roots of equations that may be of the sixth or even higher order. Consequently this stage is often omitted, since it is possible to estimate the behaviour of the system in response to non-sinusoidal inputs from the analysis in Stage 1. However, this estimation becomes less reliable as the number of time constants of the system increases above three. The mathematical analysis holds only if the system is linear, i.e. if the magnitude of the output is doubled when the magnitude of the input is doubled. Thus no account can be taken of such things as saturation of generator fields, dead zones, backlash, hysteresis, time-delays, and in fact any phenomenon tending to make the output of a unit not strictly and uniformly proportional to the input. A few mathematical theories for the performance of Stage-1 calculations for servo-mechanisms with simple non-linearities have been proposed, but their application is both involved and limited in scope, and does not give a good idea of the results which would be expected from a Stage-2 input.

It can be seen that mathematical analysis of servo-mechanisms has the following disadvantages.

1. A small degree of mathematical training is necessary.
2. The process is long and laborious.
3. No concise account can be taken of non-linearities.
4. The effect of variations in components cannot be quickly estimated.
5. The manipulation of the calculations does not give the feel of the system being designed.

Since the construction of a mathematical model is unsatisfactory, it is reasonable to construct another model which will give a clearer picture of the way the system will behave, and an analogue computer will do this—with the following advantages.

1. All non-linearities can be simulated.
2. Dead times can be incorporated in the computer.
3. The effect of changes in system components can easily be seen.

4. If necessary, the system components can themselves be used.
5. The Stage-2 responses, which are the ones which really interest the designer, can be seen on the display tube.
6. Records of system responses can be easily obtained and stored.

Functioning of the computer

Usually a computer is arranged so that either repetitive or single-shot solutions can be produced, and the repetitive solutions can consist of time periods from one second to one thirtieth of a second of real time. However, as will be seen later, although the display time of the computer is limited, the response time of

Twin-drive rolling-mill motors. Generator exciter set and control exciter set in front

the system being studied can have any value desired. The solution is displayed on a cathode-ray tube, and can be recorded by pen recorders.

Basic units of a computer

There are three basic types of unit for a computer—linear units, scaling units and discontinuous units. A linear unit consists essentially of a high-gain d.c. amplifier, together with circuitry which will reset it to its initial conditions during the 'off' period when repetitive solutions are being displayed on the cathode-ray tube. Scaling units consist of resistances of various values, which can be connected to the inputs or in the feedbacks of the linear units. The discontinuous units are essentially the same as the linear units, except that biased diodes are used so that the unit will either:

a. not fire until a certain input voltage is reached (dead zone), or

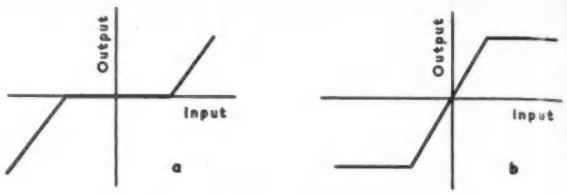


Fig. 1 Conditions in discontinuous units

b. not produce any further output when the input has reached a certain voltage (saturation). These two conditions are illustrated in Fig. 1.

Transfer functions

If scaling units and capacitors are connected in various ways in the input and feedback circuits of the linear amplifiers, various gains and transfer functions can be obtained from them. Thus, if we have the connexion shown in Fig. 2,

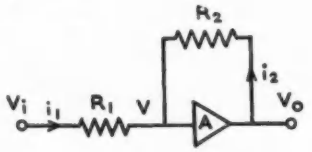


Fig. 2

where V_i, V, V_o are the voltages at the points indicated, A is the amplifier and R_1 and R_2 are resistances, then

$$\frac{V_i - V}{R_1} = i_1$$

$$i_1 + i_2 = 0$$

$$\frac{V_o - V}{R_2} = i_2$$

$$\frac{V_i - V}{R_1} + \frac{V_o - V}{R_2} = 0$$

but

$$V_o = KV$$

$$\frac{V_i - \frac{V_o}{K}}{R_1} + \frac{V_o - \frac{V_o}{K}}{R_2} = 0 \qquad \ldots (1)$$

and providing K is made sufficiently large $V_o = -\frac{R_2}{R_1}V_i$

i.e. zero time constant and gain $\frac{R_2}{R_1}$

Similarly for the connexion shown in Fig. 3

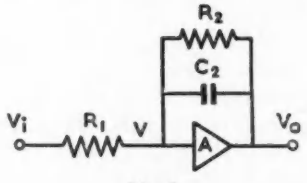


Fig. 3

$$\frac{V_i}{R_1} + \frac{V_o(R_2 + 1/CD)}{R_2/CD} = 0$$

$$\frac{V_i}{R_1} + \frac{V_o(1 + R_2CD)}{R_2} = 0$$

$$V_o = -\frac{R_2}{R_1}\,\frac{V_i}{(1 + R_2CD)}$$

This transfer function has a time constant of R_2C and a gain of $\frac{R_2}{R_1}$. In practice C_2 will be of the order of microfarads and the resistances will be of the order of megohms, giving time constants of the order of one second. There is no reason why this time should not represent an actual time constant of one hour or any other unit of time, but this will preclude connecting components of the system into the analogue.

When the differential coefficient of the output of a certain unit is required it has been found inadvisable to use the connexion shown in Fig. 4

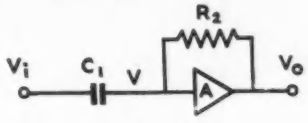


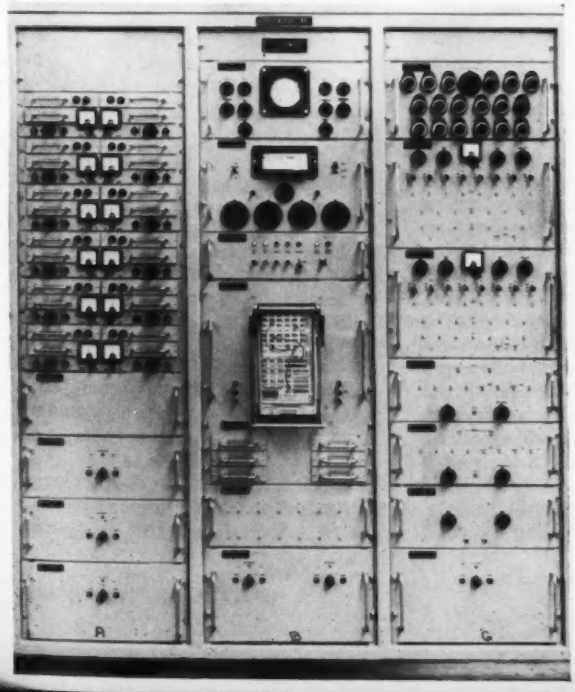
Fig. 4

which theoretically should give the transfer function

$$V_o/V_i = R_2C_1D$$

In fact this connexion is not satisfactory because there is bound to be some high-frequency noise in the output of the preceding amplifier, and this will pass easily through the capacitor and be magnified out of proportion. A method of avoiding this trouble is illustrated in Fig. 5. A feed-forward is taken from the input to the amplifier B which precedes the function of which the differential coefficient is required. This is subtracted from a proportion of the output of B, and provided these two inputs are in the correct ratio the output will be proportional to the differential coefficient of θ.

A typical analogue computer: the English Electric Lace Mk. II



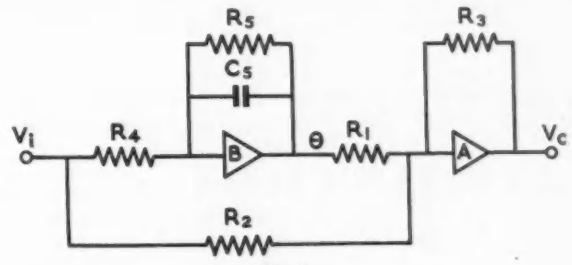


Fig. 5

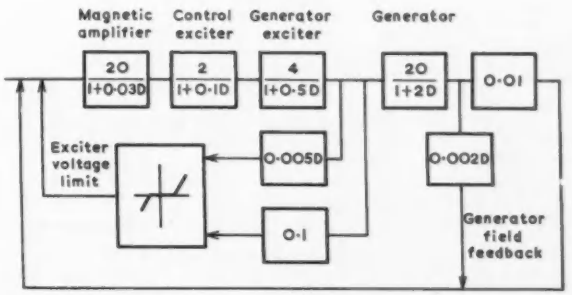


Fig. 6 Block diagram of voltage control of main drive generator

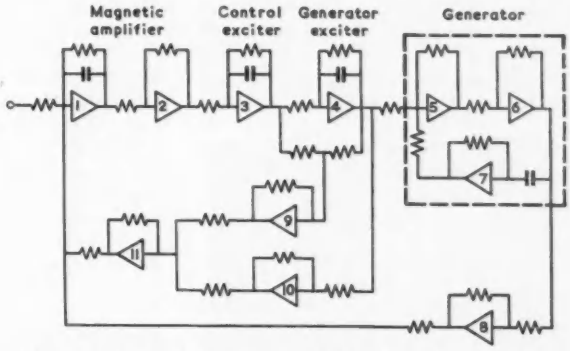


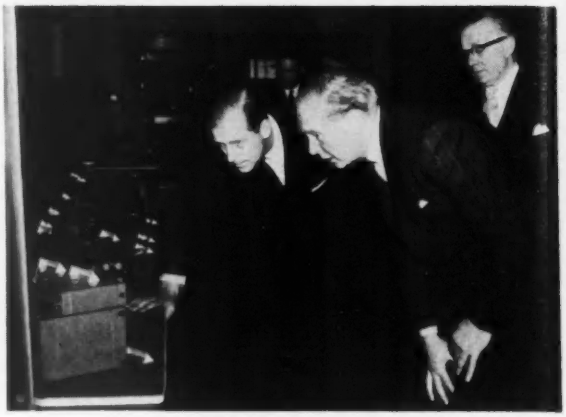
Fig. 7 Analogue of voltage control of main drive generator

Illustrated in Fig. 6 is an example of the block diagram for the voltage control of a main drive generator. The numerators in the various boxes represent the gains of the units, and the coefficients of D in the denominators are the time constants. The generator-field feedback signal is used for stabilizing the voltage control, and the exciter voltage limit is used for controlling the rate of rise of the generator volts. The analogue of this block diagram is shown in Fig. 7. In this diagram amplifier 2 will be a discontinuous unit which will produce the characteristic of saturation which is obtained with a magnetic amplifier. Amplifiers 3 and 4 will not have any limitations on their excursions since it is assumed that their characteristics are sufficiently linear over the working range. Amplifiers 5, 6 and 7 will represent the behaviour of the generator of which the flux:magnetizing-current curve will show an appreciable degree of saturation.

To be continued

PEOPLE IN CONTROL

by Staffman



H.R.H. POTTER GORDON-SMITH
Talking of things navigational

Brigadier **J. D. Haigh,** who has just been appointed Divisional Manager of Plessey's Capacitors and Resistors Division, Swindon, tells me that 'the demand for high-quality components for professional use is increasing rapidly, and we are gearing-up to meet this demand. Great interest is being shown by the computer people in our new metal-film resistors.' I asked him if he would care to estimate the proportions of Plessey components going to domestic and industrial users. He replied that this varied from product to product, but 'if we consider variable resistors, as an example, the industrial user is probably taking between 30% and 40% of our output.'

SANDIFORD

HAIGH

Under one umbrella

Other Plessey Group news includes **K. R. Sandiford's** appointment as General Manager of Hagan Controls. He was Chief Instrument Engineer of the U.K.A.E.A.'s Development and Engineering Group, and during the war was responsible for the entire production of fire control instruments for British coastal artillery. I gather that Hagan Controls' activities will embrace the whole field of automatic control.

E. G. Wakeling, who is General Manager of Advance Components, has been elected a Director of that company. He was manager of Elliott's Servo Division and joined Advance in February 1959. He explained to me that Advance were probably best known as manufacturers of measuring equipment for the radio communications field, but that they were now entering more and more into industrial electronics and control.

The **Duke of Edinburgh** visited Smith's Cheltenham factory on February 25, and my heading illustration shows **G. B. G. Potter** (Managing Director, Smiths Aviation, Marine and Industrial Divisions) discussing an exhibition of aeronautical instruments with him. S. Smith and Sons' Chairman, **Ralph Gordon-Smith,** is on the right. There is no doubt that H.R.H. does an excellent job for British industry, although I suspect that his personal interest in things navigational made the Smiths visit rather more enjoyable than many of his courtesy visits to industry.

Fischer & Porter have re-organized their sales force. There are now three Regional Managers under the Sales Manager, **D. Y. Smith: J. W. Borkett** covers the south of England from an office in Harrow, **F. Higgins** will take care of the Midlands from Manchester, and **R. D. Nixon** covers the northern region from an office in Stockton-on-Tees. **J. W. Fairbairn** will continue to handle Scotland as he has done for the past two years.

A new company set up jointly by Southern Instruments and Drayton Regulator, and known as Drayton-Southern, interested me, so I asked **J. G. Lubbock,** Managing Director of Drayton-Southern and local director of Drayton Regulator, for details. He tells me that the intention is to extend the instrument business of both parent companies by marrying Southern's mainly-electronic skills with Drayton's mechanical skills. They will manufacture a range of equipment some of it of American origin. An example of the latter is the 'Omniguard' temperature and pressure monitoring system of the American Thomas A. Edison company. Drayton Regulator's Chairman, **P. H. Lloyd** is Chairman of Drayton-Southern and other members of the Board include Southern Instruments' Chairman, **R. D. Poore,** and Southern's Vice-chairman and Managing Director, **Phillip Sellars.**

Incidentally, Major General **Sir William A. Scott** has joined Southern Instruments' Board. He was Director of Communications at the Foreign Office and before that was Director of Weapons and Development at the War Office. I gather that he will act in an advisory capacity to the Southern Board.

Ultra Electronics' recently-appointed Projects Manager, **F. W. Holmes,** tells me that he spent twenty years in the Fleet Air Arm prior to joining Ultra. He now controls four project teams,

SAMUELS

YATES

Designs for living

each of which is responsible for the sales, engineering liaison and progressing of its own particular product. The four teams cover 'controls'—both aero-engine and industrial, 'communications,' 'data processing,' and 'anti-submarine and beacons'—including radio/radar navigational devices.

Appointed Works Director in charge of production at Winston Electronics, **Joseph Samuels** (ex-S.T.&C. and

Sunvic), joined Winston's Board in 1956. I asked him to comment on the problems of producing electronic instruments. 'Let's be more general than that,' he said, 'I am interested in output and this depends upon a happy atmosphere in the factory with no bickering or jockeying for position.'

'The smaller company can supply a very definite service' according to **Frank N. Yates,** who is now Seton Creaghe Engineering's Commercial Manager. Yates (ex-Sunvic, and Fischer & Porter) tells me he finds his work at Seton Creaghe most stimulating. 'We go in for small specialist design and manufacture of electrical and mechanical instruments, and this gives me a more intimate relationship with the user than is possible in larger organizations.'

I was interested to hear that Measuring Instruments (Pullin) had retained **Gunther Hoffstead** as a design consultant. I gather that he will collaborate with M.I.P.'s Development Department, who are responsible for engineering design, the idea being that Hoffstead's visual design must be dependent on the function and operation of the instruments. Incidentally, **John Guy** (ex-Sifam Electrical) has been appointed M.I.P.'s Chief Planning Engineer.

AUTHORS IN CONTROL

E. W. Jones (*Nucleonic measurement of level*, page 88) graduated with First Class honours in Physics from the University of Wales, Aberystwyth, in 1949. During the war he worked at the Telecommunications Research Establishment, Great Malvern, mainly on microwave aerials and wave guides. In 1946 he transferred to A.E.R.E. Harwell, where he worked on the design of a synchro-cyclotron and, later, in the Isotope Division. He joined Isotope Developments on the foundation of that company in 1950. There he has been responsible mainly for pioneering industrial applications of radio-isotopes including thickness gauges, level gauges, and automatic packing inspection equipment. At present he is the company's Chief Physicist.

G. Field (co-author with S. R. Barker —below—of *Automatic control in the cement industry*, page 91) served as a meteorologist in the Royal Air Force, prior to resuming his science studies at University College, London. He joined the staff of Associated Portland Cement Manufacturers Ltd., in 1950 and for the past seven years has been engaged in plant and process research at their Central Research Laboratories.

S. R. Barker joined the Research Department of A.P.C.M. in 1937. During the war he served as a pilot in the Royal Air Force, latterly being concerned with the flight testing of aircraft. He transferred to the R.A.F.'s Signals Branch and served as a Signals Officer until 1946, when he rejoined A.P.C.M. Since then he has been engaged in plant and instrument research.

R. B. Sims (*Load cells in industrial weighing*, page 94) graduated at the University of London in Physics and Mathematics. After serving with the Royal Air Force as a meteorologist for seven years he completed an engineering apprenticeship with Baker Perkins of Peterborough, and joined the British Iron and Steel Research Association in 1948. From then until 1952, Dr. Sims was Head of Bisra's Rolling Mill Laboratories. He completed work on the calculation of roll force and torque in both hot- and cold-rolling mills, but his main contribution to rolling-mill studies has been an analysis of the cause of thickness variations in mills and a design of automatic gauge control called the 'Gaugemeter' system which is used widely throughout the world. Part of this control system uses a loadmeter for measuring the roll-separating force between the rolls whilst the metal is being deformed, and it was the need for an accurate and reliable instrument which gave rise to the research, the results of which are contained in the present article. He became Research Manager of Davy and United Engineering in 1953, General Manager of the Instrument Division in 1956, and Chief Engineer, Research and Development, in December 1958. He retained his Directorship in the Instrument Company when it was formed from the Instrument Division in 1959. Dr. Sims was awarded his Ph.D. for work on the theory of cold rolling and automatic gauge-control in cold mills.

Michael B. Wood (co-author with J. Baldwin—below—of *Digital recording multi-point pressure surveys*, page 97) studied electrical engineering in the College of Technology at Manchester University, but became an instrumentation engineer after joining the Aircraft Research Association, Bedford, in 1955. There he worked on automatic digital-data recording and instrumentation for wind-tunnel testing, and spent some time on digital computers. He is now with Ferranti, Wythenshawe, engaged on the application of digital computers to industrial process control.

J. Baldwin joined the staff of the Aircraft Research Association as a Junior Instrumentation Engineer in October 1955. He has had experience of designing and building all A.R.A. data-handling equipment. In November 1957 he started investigation on automatic pressure recording with M. B. Wood. In mid-1959 he investigated a high-speed recorder, and the equipment is scheduled for use in the Spring of this year.

T. B. Wearden (*Gearhead ratio selection in servo-motor drives*, page 102) graduated from Manchester University with Honours in Electrical Engineering. After service in the Royal Navy as an electrical officer, he joined Ferranti, Edinburgh, as a sales engineer and later worked in Ferranti's Computer Department as a development engineer on computer peripheral equipment. He joined Vactric Control Equipment as Midland area sales engineer in January 1959.

R. A. Brooker (*The ultimate basis of control*, page 107) graduated at the Royal College of Science, London, then spent two years designing and partly building a relay computer; this was followed by two years at the University Mathematical Laboratory, Cambridge, working first on the differential analyser, and later on the Edsac I. Since 1951 he has been at the Computing Machine Laboratory, Manchester University, where he is now Senior Lecturer in the Theory of Computing. He has worked mainly in the field of numerical analysis, programming and logical design of machines.

CONTROL IN ACTION

Australian power station remotely controlled

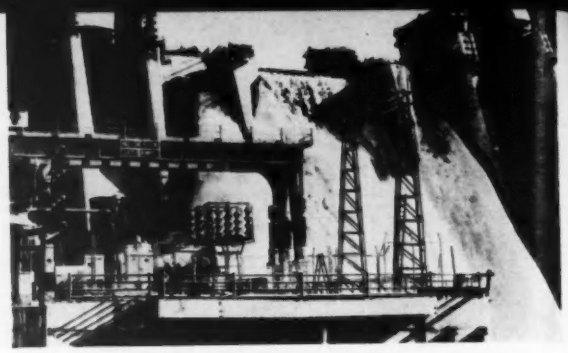


Fig. 1 The 50 MW hydro-electric power station at Warragamba Dam, New South Wales

Hydro-electric station controlled by 48-mile link

THE NEW SOUTH WALES ELECTRICITY Commission's 50-MW hydro-electric power station at Warragamba Dam, can be controlled remotely from Sydney, 48 miles away. The station, which cost around £M3, and took three years to build, employs generating equipment by English Electric, who supplied and installed it at a cost of about £M1.

The operation of the Warragamba station depends upon the availability of water behind the dam, so that it is not a base-load station. Power will only be generated when the water level is high enough to be more than sufficient for Sydney's water-supply needs. After heavy rain, for example, the station may operate for long periods, but if the level is low, power will be generated during the morning and evening peak periods only. It follows that the station will be required to feed power into the State network at somewhat irregular intervals, depending on the conflicting needs of the Sydney Water Board and the N.S.W. Electricity Commission, thus making remote control from Sydney mandatory.

The English Electric turbo-generator at Warragamba may be used either to generate power or as a synchronous condenser set. In the latter case, of course, after the generator has been brought up to speed by the water turbine, the water flow is cut off and the generator operates as a synchronous machine.

Starting the turbine

The automatic starting sequence may be initiated by closing the local starting switch, or remotely by means of a radio link from Sydney. In either case, a master control relay is energized and this in turn operates an auxiliary control relay. The latter brings into operation the main oil pumps for the governor, the turbine, and the generator. D.C. standby oil pumps are also prepared for operation so that they will take over should the flow of lubricating oil cease for any reason.

When the set is stationary the generator is heated electrically, and, on starting up, the auxiliary control relay switches these heaters off. The master control relay energizes the main start bus causing the main motor-operated cooling-water valve to open. Water then flows through the oil coolers, the cooler for the main shaft bearings and the air coolers for the alternator. The 'excessive starting-time' relay is also energized from the main start bus.

The master control relay also causes a motor-operated valve in the turbine's spiral casing to open in order to release the air within it, and a further motor-operated by-pass valve opens to allow water to flow into the spiral casing. As the casing fills, the pressure builds up until a pressure device is actuated, and this causes the air release valve to close again, and also controls a hydraulic servo-motor so that the main butterfly valve opens. When the latter is fully open, a limit switch operates to open a solenoid actuated valve which controls the oil supply to the governor's actuator.

The guide vanes, which regulate both the direction and rate of flow of water to the turbine, then open slowly under the control of the governor and its hydraulic servo-motor system. Water flows through the turbine which accelerates to reach 50% of full speed, when a speed-measuring relay brings in various interlocks and the governor gradual-start device is isolated to permit the turbine to attain no-load speed. The excessive starting time relay is then de-energized.

Generator operation

The closure of a pressure-operated contact on the governor indicates that the governor has taken over full control and initiates the next stage in the starting sequence. The control exciter and high frequency motor-generator set is started and a 'ready-to-synchronize-timing' relay is energized.

A master control-relay contact causes the main exciter stabilizing field to be energized, and the output voltage of the alternator increases to the a.v.r. setting. This voltage energizes under-voltage relays which act as interlocks in the automatic voltage regulation lock-out circuit and the 415-volt auxiliary board automatic supply change-over control circuit.

The operation of the time-delayed 'ready-to-synchronize' relay prepares the automatic synchronizing control circuit and indicates 'ready for synchronizing.' Operation of the synchonizing push-button brings in automatic rapid-synchronizing gear, which adjusts the generator speed and voltage to match the system conditions and, at the right moment, initiates the closing of the main 132 kV oil circuit breaker. Breaker auxiliary switches prepare various alarm circuits and also trip the incoming feeder breaker to the 415-volt board. A time-delayed change-over relay then closes the unit transformer breaker, restoring the supply to the 415-volt board.

The desired generator power-output may be obtained by adjusting the governor, and the reactive power output by means of the a.v.r. setting.

A maximum amount of guide-vane opening may be imposed by a load limiting control. This feature is of particular importance as the storage capacity provided by Warragamba is primarily for the Sydney water supply.

Shutting down the generator

The automatic stopping sequence, which is initiated similarly to the starting sequence, causes the master control relay to reset. The automatic

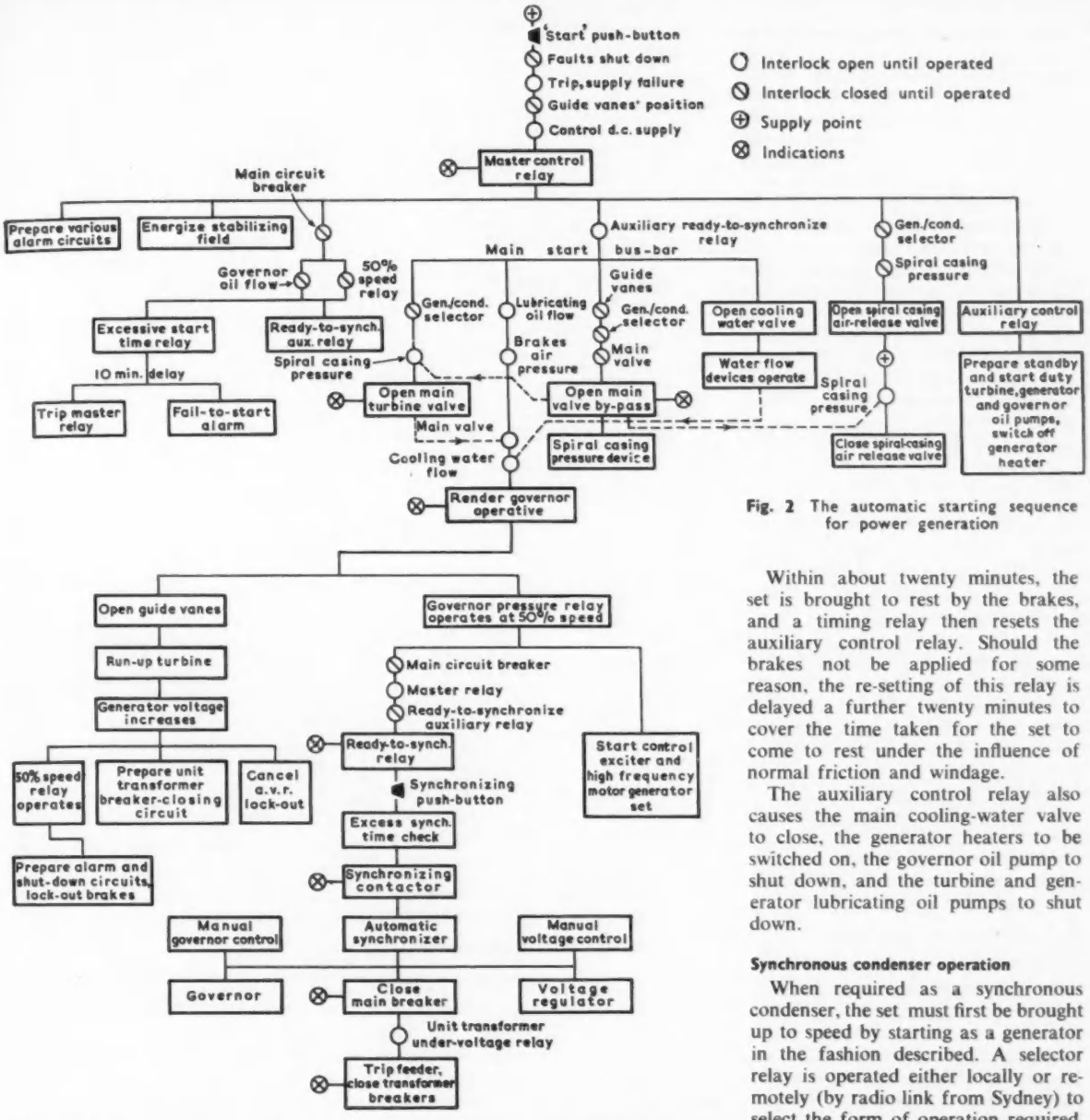


Fig. 2 The automatic starting sequence for power generation

'lower' control circuit of the governor speeder motor is energized, and the governor setting reduced. This, in turn, causes the guide vanes to close and cut off the flow of water through the turbine. When the guide vanes are fully closed, a limit switch contact closes to energize the main breaker trip coil. The breaker-trips isolate the generator from the system, and a breaker auxiliary switch closes the governor-actuator oil valve by energizing the main stop bus-bar. This renders the governor inoperative, and causes the governor oil pressure relay to re-set. The latter shuts down the control exciter and high frequency motor-generator set.

Energizing the main stop bus-bar also causes the main turbine butterfly valve to close. When this is fully closed a limit switch causes the butterfly valve by-pass valve to close.

The auxiliary switches on the main breaker also, de-energize the speeder motor and several alarm circuits, and trip the unit transformer breaker. The incoming feeder breaker closes after a short time delay to restore the supply to the 415-volt board. The main exciter stabilizing field is de-energized by the master control relay.

As the set slows down to about half-speed, the speed-measuring relay energizes the solenoid which applies the compressed-air-operated generator brakes. The contacts of this relay also open some of the alarm circuits.

Within about twenty minutes, the set is brought to rest by the brakes, and a timing relay then resets the auxiliary control relay. Should the brakes not be applied for some reason, the re-setting of this relay is delayed a further twenty minutes to cover the time taken for the set to come to rest under the influence of normal friction and windage.

The auxiliary control relay also causes the main cooling-water valve to close, the generator heaters to be switched on, the governor oil pump to shut down, and the turbine and generator lubricating oil pumps to shut down.

Synchronous condenser operation

When required as a synchronous condenser, the set must first be brought up to speed by starting as a generator in the fashion described. A selector relay is operated either locally or remotely (by radio link from Sydney) to select the form of operation required.

When the set acts as a synchronous condenser the flow of water is cut off, and the draft tube pressurized with air to depress the water level clear of the turbine runner. The inherent cooling facility is thereby lost, so the selector relay opens a valve to permit cooling water to reach the runner crown.

The speeder motor local-control switch, or the equivalent Sydney control, is operated to reduce the governor setting, which in turn causes the guide vanes to close. A guide-vane limit-switch then closes to complete a circuit via a selector relay contact and energize the main stop bus-bar. This in turn causes the main butterfly valve to close, and a butterfly-valve

limit-switch closes the by-pass valve.

When the by-pass valve is closed, limit switches close to indicate 'ready for synchronous condenser operation' and also to energize the draft-tube water-level control circuit. If the level is too high, the conductivity of the water causes a current to flow between two electrodes set in the draft-tube wall, and a relay is energized to operate a solenoid and thus open a valve to admit compressed air to the draft tube. The water is then depressed until the circuit between the electrodes is broken, when the air supply is shut off.

The excitation is then adjusted by means of the voltage-setting rheostat control to achieve the desired reactive power loading. When shutting down from synchronous condenser operation, the reactive power loading is first reduced to zero manually by means of the voltage setting rheostat control. The master control relay is then reset, as when shutting down from generator operation. The main breaker is tripped by a master control relay contact, and the change-over of supply to the 415-volt board is effected as before.

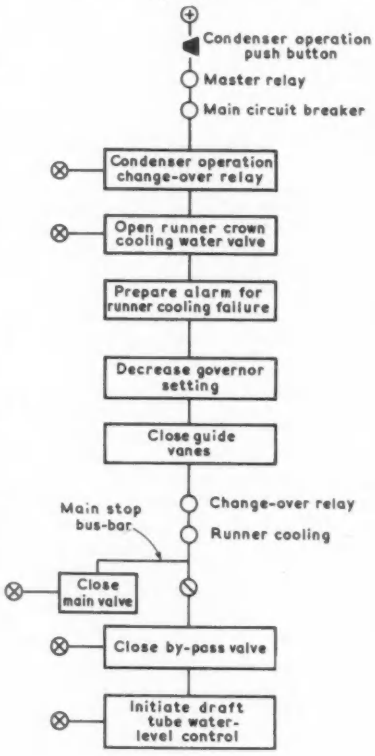
The master control relay also shuts down the compressor for draft-tube pressurization, trips the stabilizing field contactor, and resets the generator/synchronous condenser operation selector relay. The selector relay, in turn, closes the governor actuator oil-admission valve. The loss of oil pressure causes the oil pressure device to operate and this shuts down the control exciter and high-frequency motor-generator set.

The selector relay also shuts down the draft-tube water-level control circuit, and closes the runner-crown cooling water valve.

The speed-measuring relay applies the brakes at about half full-speed, and when the set has come to rest, the auxiliary control relay is reset. The flow of cooling water is cut off, the generator heaters are switched on under thermostatic control, the governor oil pump stopped, and the generator and turbine lubricating oil pumps shut down.

It will be appreciated that the automatic and remote operation of these complicated starting-up and shutting-procedures, for both generator and synchronous-condenser operation, is no mean feat. The controls themselves are not particularly complex but the fact that the system works efficiently despite the multiplicity of individual controls speaks well of their reliability.

Fig. 3 Automatic change-over from generator to synchronous condenser operation



CONTROL IN ACTION

A practical motor vehicle telemetry system

by A. POTTEN, B.Sc.

IN THE PAST, NO SATISFACTORY method of measuring temperatures, pressures, etc., in a moving motor vehicle has been available. Direct recording techniques involve carrying the recording equipment in the test vehicle itself, or in a second vehicle attached to the test vehicle by means of a length of cable. These methods have basic disadvantages when safety, reliability and accuracy are considered.

Examination of the problems involved in the measurement of physical quantities inside a moving vehicle, indicated that a multi-channel telemetry system would overcome the difficulties encountered with previous techniques. In view of this, a four-channel system was developed by Sir W. G. Armstrong Whitworth Aircraft to test the feasibility of telemetry for use by vehicle designers in the motor industry. Four channels was considered to be the minimum number for assessment of the scheme but further channels can easily be added.

A block diagram of the sender unit is shown in Fig. 2. A time-multiplex (p.a.m.–f.m.–a.m.) system is used, which employs a frequency-modulated sub-carrier to amplitude-modulate a transmitter with a carrier frequency in the decimetre band. A 10 h.p. car was originally used as a test vehicle and is fitted with four transducers comprising two strain-gauge units, one thermocouple and one thermistor. The strain gauges are fitted to one track rod and one steering arm, and are in pairs—one active and one passive element—to compensate for temperature changes. A thermocouple is fitted to the exhaust manifold and a thermistor measures the temperature of the oil in the sump.

The low-level outputs from strain-gauge and thermocouple circuits are connected to channels 2, 3 and 4 of bank 1 of a double-bank 24-channel telemetry sampling switch. The output from bank 1 is amplified by a thermostabilized low-drift d.c. amplifier and fed to segments 2, 3 and 4 of bank 2 of the switch. At this point, a synchronizing voltage source is connected to segment 1 of bank 2 of the switch

Fig. 1 The sending unit weighs 30 lb and will fit easily in the front seat

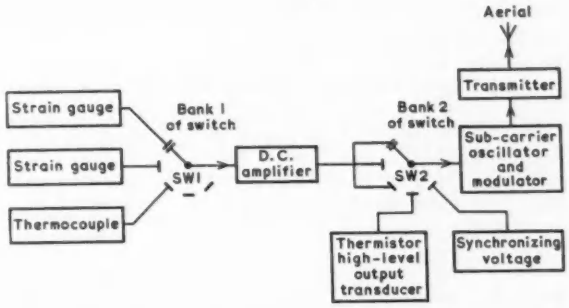


Fig. 2 Four transducer-signals are sampled in telemetry fashion, prior to transmission

and the thermistor output is connected to segment 5 of the same bank.

The output from bank 2 modulates the frequency of the sub-carrier oscillator, and the latter amplitude-modulates a u.h.f. oscillator. The signal is transmitted via a monopole aerial fitted to the roof of the vehicle.

The receiving station is shown in Fig. 3 and diagrammatically in Fig. 4. A standard A.W.A. u.h.f. receiver type UR 1 is used and the detected signal fed to a frequency discriminator. The discriminator output is displayed on a cathode-ray tube for visual monitoring of the signal. After discrimination, the signal is de-multiplexed in the strobing system and the individual channels recorded on ultra-violet recorders—the N.E.P. Series 1050.

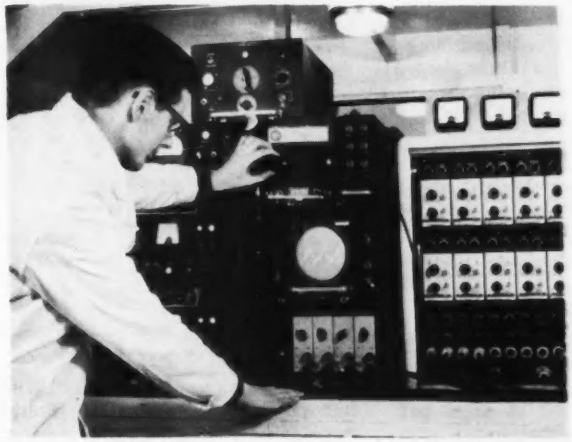


Fig. 3 The receiving station of the vehicle telemetry system

Transducer circuitry

The modulator requires a single-ended input going positive and negative about earth and the transducer circuitry is arranged to give this type of output. A further restriction is that in order to satisfy the bias requirements of the input stage of the d.c. amplifier, signals must be presented to a resistance of 1 kΩ. Supplies for the transducers consist of a 12-V positive and 12-V negative stabilized supply.

As will be seen in Fig. 5, the strain gauges are connected in half bridge circuits, with one passive and one active element. A variable resistance balances the system and 2 kΩ Rotol strain gauges are used. From an estimate of the strains involved, an output from the strain-gauge circuits of ± 10 mV at maximum strain was expected. A similar output was also anticipated from the thermocouple circuit. The output from the thermistor circuit is, however, ± 1·5 V over the expected temperature range and amplification is not therefore required.

D.C. amplification

The d.c. amplifier consists of two stages, each stage comprising an emitter-coupled pair. This configuration reduces effects due to the thermal drift of individual transistor parameters. Thermal-drift effects are further minimized by the use of a temperature-sensing element which controls the current through the heater of a temperature-controlled block. Variations of ambient temperature are reduced by a factor of 10 inside the block and the transistors within it are maintained at a steady 40°C. Since noise in a mechanical switch depends partly on the current through the contacts, the amplifier is arranged to draw no current from the input source for zero input-level.

The gain of the amplifier is variable with a maximum of 240, and zero-level drift is equivalent to 10 μV at the input for every 1°C change in ambient temperature. The output of the amplifier is 3 dB down at 50 kc/s.

The telemetry transmitter

The frequency modulator section of the transmitter is of conventional reactance-valve type. The input to the modulator controls the frequency of the sub-carrier oscillator by means of the reactance valve. Amplitude modulation is accomplished by feeding the sub-carrier output to the grid of a valve in series with the transmitter. The u.h.f. transmitter uses two A1714 valves in push-pull with a quarter-wave lecher line. Loop coupling is employed at the output of the transmitter and the signal is fed to a monopole aerial on the vehicle. The maximum power output of the transmitter is 1·5 watts and the range is well over two miles. The maximum frequency of the information transmitted is 60 c/s at present.

The sending unit as a whole weighs 30 lb and, as can be seen in Fig. 1, will fit easily into the front seat next to the driver. The equipment can be operated by the driver alone, making it unnecessary for a second operator to be carried.

Reception, display and de-multiplexing

A folded dipole with a single reflector is employed as a receiving aerial. The bandwidth of the A.W.A. receiver is 4·5 Mc/s which, although excessive for the immediate application, may be useful for future high-information systems.

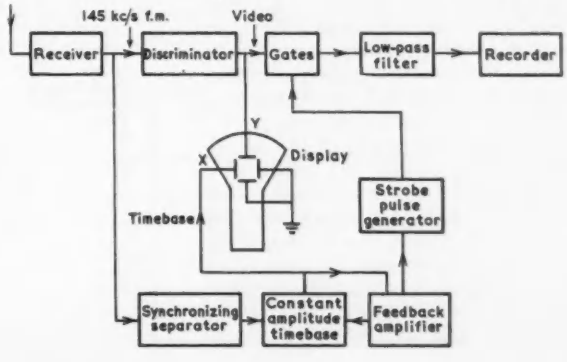


Fig. 4 Telemetry signals are displayed visually and, after de-multiplexing, recorded

After detection, the signal is passed into a Travis Round discriminator, which is a simple balanced type utilizing two circuits tuned to frequencies above and below the sub-carrier centre frequency. The output from the discriminator is in the form of a telemetry histogram which is displayed on a cathode-ray tube to enable the signal to be visually monitored before de-multiplexing. The display system also separates the synchronizing channel from the composite signal and uses it to lock the visual display.

De-multiplexing of the composite signal is carried out with the aid of a 'strobing' unit and a gate of the 'sample and hold' type. The gate output is a stepped wave, and this is passed through a low-pass filter via a cathode-follower buffer stage. Since the cut-off frequency of the filter is 60 c/s, the output from the filter is no longer a stepped waveform, and all frequency components of the original signal up to 60 c/s appear at the output. The maximum output voltage from the filter is ± 15 V across the 30 kΩ input resistance of the recording unit.

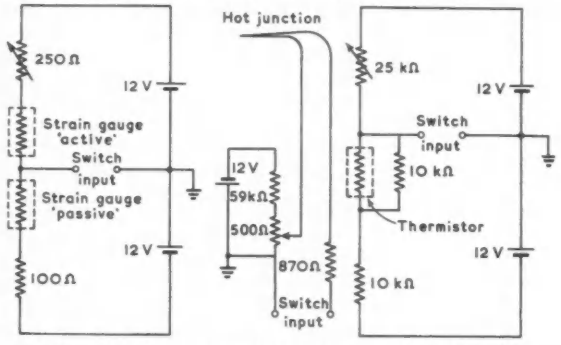


Fig. 5 Transducer circuitry: note that strain gauges are connected in half bridge circuits

Performance of the system

The system has been extensively tested under field conditions. A 10 h.p. car was used as a test vehicle initially and the equipment has been tested over all types of road conditions. No failure of the equipment due to road conditions has been experienced.

From the point of view of the vehicle designer, the system would appear to be attractive, since the records received do not require complex manipulation to be reduced to the respective physical parameters. The system is linear throughout and deflexions of the trace on the record are directly reducible to variations of the physical quantities involved, by multiplication by a constant. A typical record received on a test run is shown in Fig. 6. With the system at present, the overall accuracy is approximately 5%, but with further development this could be improved to better than 3%.

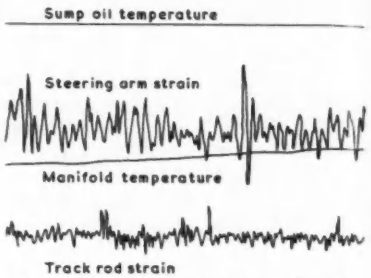


Fig. 6 A typical motor-car telemetry record

The author's thanks are due to Sir W. G. Armstrong Whitworth Aircraft Ltd., and to his colleagues, B. Graham and D. Richardson for their invaluable design assistance. Thanks are also due to J. E. Dick and F. Exley for their advice and encouragement.

CONTROL IN ACTION

Pre-set control for guillotine

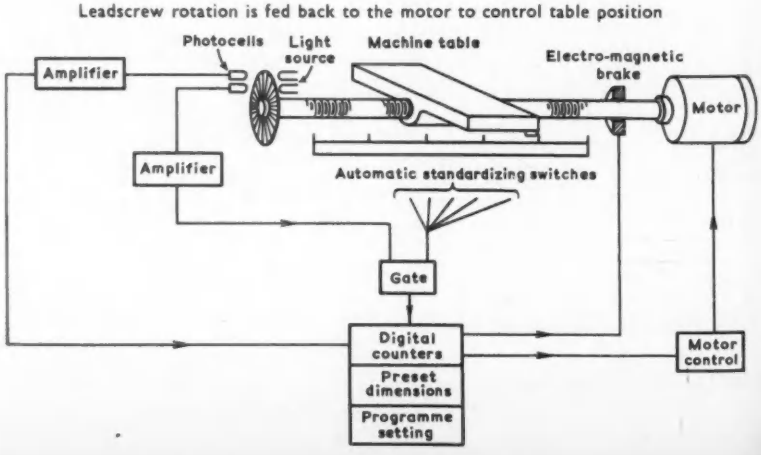
A CO-ORDINATE POSITION-CONTROLLER for machine tools made by James Scott & Co., is used to control the John Greig 54 in hydraulic self-clamp paper guillotine, performing a cycle of operations according to a pre-set programme. The guillotine has a flat bed in which the paper to be cut is placed, and a movable fence driven by a leadscrew is used to push the paper to the correct cutting position.

In order that the paper should be cleanly cut the fence-stopping operation should be in two parts. First, the motor speed is reduced to well below normal drive speed at a point prior to cutting. Secondly, the fence must be stopped at cutting position.

The main sensing head is a photocell which monitors the setting of a disk attached to the leadscrew. Absolute calibration of the machine setting during operation is by a second photoelectric unit operating in conjunction with a series of switch units mounted at intervals along the bed of the machine. The accuracy of this controller is a function of the leadscrew pitch and the number of digits per rotation of the leadscrew. In this case a ½ in. pitch leadscrew is used, with 500 digits per revolution, thus giving a system sensitivity of 0·001 in.

The output from the photoelectric sensing head is fed to two sets of Dekatron counters. One bank of counters is used to measure the absolute position of the machine bed, and is corrected at regular intervals by the standardizing mechanisms. The other counter is for measuring relative motions only, such as are required when labels are being cut.

The counter units are continuously monitored and compared with the setting of the input switches. When the dimension set is being approached the controller switches a 'slow-down' signal to the motor, and then at the correct dimension a brake is applied, and the motor is stopped.



A monthly review—under basic headings—of the latest control engineering developments for all industries; specially edited for busy technical management, plant and production engineers, chemical engineers, etc., who are not specialized in instrument and control systems

IDEAS APPLIED . . .

. . . to MULTIPLICATION

R. P. CHASMAR, Research Department, A.E.I. (Manchester) Ltd.

A multiplier has been developed in the semiconductor research laboratories of A.E.I. (Manchester) that performs the multiplication of two electric currents with an accuracy of 0·1%. The operation is based on the well-known Hall effect in a semiconductor, whereby a plate of the material carrying a current, and placed in a magnetic field, generates a voltage between suitably disposed contacts which is proportional to the product of current and magnetic field strength. In the unit described the semiconducting plate is mounted in the gap in a ferrite core, and the magnetic field is produced by a current flowing in a winding on the core.

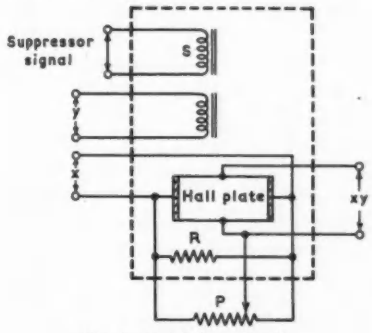


Fig. 1 Multiplier circuit

The circuit diagram of the multiplier is given in Fig. 1. Current x in the plate and y in the main coil produce a voltage proportional to xy across the Hall electrode connexions. The maximum value of the output voltage is of the order of 0·1 V, this being produced by a plate signal of 300 mA and a coil excitation of 60 A-turns. The semiconductor used exhibits a large Hall effect with a particularly small temperature-coefficient. By means of a positive temperature-coefficient-resistor, R, shunted across the plate, the temperature performance is further improved to give an overall coefficient of the order of 0·02%/°C.

In principle, the Hall effect is a perfect multiplication system. In practice, errors arise due to non-linearities in the relation between coil current and magnetic field. Measurements of harmonic distortion in the Hall output, when an alternating current is supplied to the coil and a direct current to the plate, show more than 50 dB discrimination between fundamental and the largest harmonics. When the coil is supplied with d.c., however, the departure from perfect linearity is greatest and the degree of non-linearity is 1%, as estimated from the shape of the hysteresis loop. This may be reduced by a method similar to that used for the suppression of hysteresis in magnetic-tape recorders, in which an alternating flux, sufficiently great to overcome the coercive force of the magnetic core, is superimposed on the working signal. A separate 'suppression' coil, S, is provided for this purpose, and should be supplied with a.c. of a frequency sufficiently above the normal frequency range of operation to be filtered out easily in subsequent circuits. By this means an overall linearity of 0·1% may be achieved.

Drift effects and direct breakthrough of coil signal into the output circuit can be very troublesome in Hall effect devices. In this multiplier these effects have been reduced to below 100 μV, under normal working conditions. Out of balance voltage due to misalignment of the Hall con-

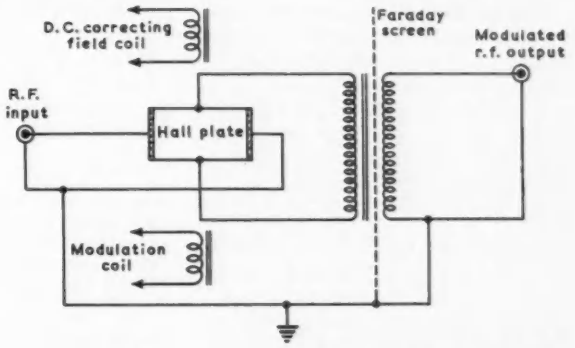


Fig. 2 Circuit of the high-frequency multiplier

nexions is eliminated by means of a potentiometer, P, connected in the external circuit. The whole assembly is potted in resin and mounted on an octal value base, thus forming a small, robust and convenient plug-in unit.

Application of the multiplier to analogue computation and control problems is immediately evident, but uses in many other less obvious fields have already appeared. For example, multipliers have been applied to power and power-factor measurements at mains frequency, to airframe-flutter problems and to the measurement of the work per cycle in internal combustion engines. As a pure product modulator, giving sidebands without unwanted carrier, it may also find application in single-side-band telephony.

When used as a modulator the multiplier is limited to a maximum carrier (plate) frequency of about 100 kc/s owing to lead inductance, and also to direct break-through from the plate signal into the output circuit. A multiplier has been developed in which the

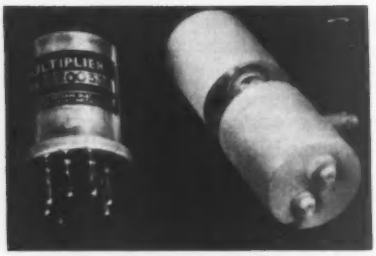


Fig. 3 Low and high frequency mutlipliers

plate is fed from a coaxial line, and by careful design the break-through at carrier frequencies up to 5 Mc/s has been reduced to a level 50 dB below maximum Hall output. The input and output impedances are substantially resistive within this range. A built-in wide-band output-transformer gives a step-up of four times to a maximum output of approximately 0·5 V, and allows the multiplier to operate into an unbalanced line. The coil assembly is similar to that provided for the low-frequency multiplier, and may be wound to operate satisfactorily up to several kc/s.

Fig. 2 shows the circuit diagram of the high frequency multiplier. An additional 'suppression' coil is unnecessary, since for a.c. operation the linearity will be adequate. A supplementary d.c. winding is provided, however, which creates a small correcting field to eliminate carrier break-through arising from any misalignment in the Hall connexions to the semiconductor plate. Applications of the high frequency multiplier may be as a carrier-suppressed modulator, in harmonic analysis, or in gain control circuits where the coil is fed with d.c.

Photographs of both the low and high frequency multipliers are given in Fig. 3.

References

1. Chasmar, R. P., Cohen, E. 'An Electrical Multiplier Utilising the Hall effect in Indium Arsenide' *Electronic Engineering*, November 1958, p. 661.
2. Chasmar, R. P., Cohen, E., Holmes, D. P. 'The Design and Performance of a Hall Effect Multiplier', International Convention on Semiconductor Devices, London 1959.

. . to ANGULAR SPEED

A circuit demonstrated by D. D. Jones (G.E.C. Research Laboratories) shows how silicon controlled rectifiers may be used to control the speed and direction of rotation of d.c. motors. Four S.C.R. 965's (two pairs connected back to back) are used in a bi-phase arrangement to provide a controlled amount of power to the armature of a d.c. motor.

The principle of operation is that variation of the phase-displacement between the firing pulses supplied to the s.c.r.'s and the incoming a.c. supply, causes the rectifiers to conduct early or late in the cycle, hence providing more or less power-output. A simple firing-control circuit, using four germanium transistors, generates firing pulses so that the devices conduct in pairs: either 1 and 2 for a positive output, or 3 and 4 for a negative output. Fig. 1 shows the basic arrangement, but does not include the firing circuit.

For convenient demonstration, a potentiometer was used to vary the firing angle of the silicon-controlled rectifier. However, a device regulated by means of a low power d.c. signal is more suitable for use in control systems. Operation by d.c. control may be achieved by inserting a saturable inductor in the phase-shift circuit, and using the d.c. control current to saturate it. This has the advantage that the firing angle is substantially independent of temperature, and that the firing circuit will operate up to a temperature of 70°C when using GET 103-type transistors. The range of control would be: motor full-forward—1 and 2 giving full positive output—through a zero point with none of the four firing (hence motor stationary), to motor full reverse—full negative output from 3 and 4.

The high surge-current handling-capacity this rectifier allows the motor to be switched directly from full-ahead to full-reverse. While the maximum continuous power-output obtainable from this arrangement is 350 W, the surge rating is over 100 A for 10 ms duration, or 60 A for 1 second, in an ambient temperature of 35°C. The circuit could therefore control a motor of greater rating in an application where fast reversing is not required.

This system may be used in place of amplidynes, Ward-Leonard sets, and similar arrangements using rotary machines. Its great advantage is that, for a given power, the controlling circuitry occupies a much smaller space than would a conventional arrangement.

Work of a like nature to that of G.E.C. is, we understand, being carried out by other firms including J. Langham Thompson.

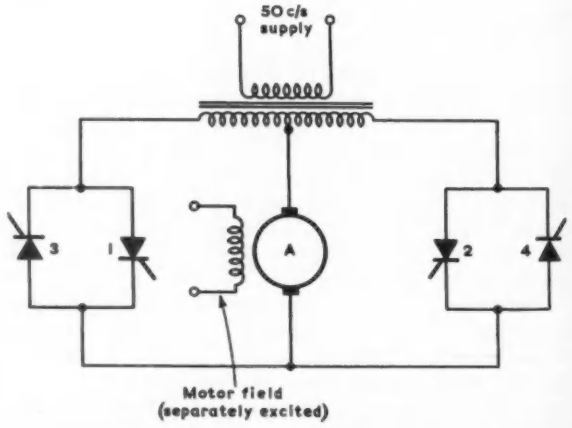


Fig. 1 Basic circuit of s.c.r. motor-control circuit

NEWS ROUND-UP

from the world of control

MISSILES

Deter and dodge

As the dust raised by the publication of the Defence Estimates settles, it is obvious that the military are unhappy about the British ballistic missile programme. The most obvious change is that—somewhat belatedly—it is now thought these weapons should be mobile. The cost of putting underground the liquid-fuelled *Blue Streak* ballistic missile, and the various ancillary equipments which make up the weapon system, is prohibitive. In any case, the so-called 'hard' base is not hard enough to resist a saturation nuclear attack. Work on *Blue Streak* is, however, to continue, for the time being at least.

Air-launched missiles

It seems to be agreed that the deterrent must be truly mobile if it is to be really effective. This requirement for 'massive and terrible retaliation' is at present met by the V-bomber force, and for some years to come will be carried out by Victor II aircraft capable of launching *Blue Steel*. The latter is the Avro stand-off bomb, a powered device which can be launched 300-odd miles from its target. However, the continuous improvement of surface-to-air defensive weapons means that *Blue Steel* has a strictly limited operational life before it. The Government is known to be interested in an American air-launched ballistic missile called *Skybolt*, and either this weapon, or a similar device of British design, looks like being the next stage. The air-launched ballistic missile could considerably extend the life of the V-bomber force. It provides essential mobility, the cost although great would not appear to be prohibitive, and it appeals to the air marshals. Doubtless it will not be long, however, before the R.A.F. publicize their need for a new dual-role aircraft which can be used either as a transport or as a ballistic-missile launcher.

Submarine-launched missiles

The naval view is that the mobile deterrent should be in the form of the American *Polaris*, an under-sea-launched ballistic missile carried by nuclear submarines. The cost of the submarines and the development of the weapons would be so enormous that many think it quite out of the question. Furthermore, it is doubtful that a *Polaris*-launching submarine would be of much value in 'conventional' warfare—unlike a missile-launching transport aircraft. However, the Royal Navy is said to be in fairly close touch with the U.S. Navy on this matter. It is also possible that some adaptation of *Blue Streak* might be developed for submarine-launching.

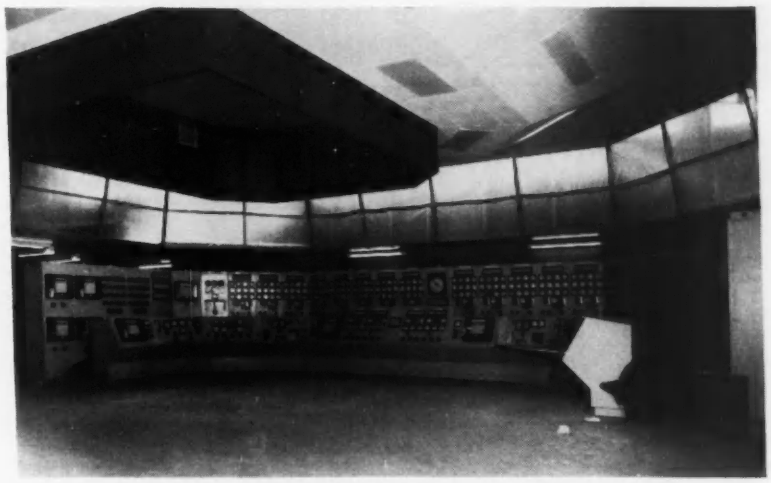
The present situation

The various guided weapons deployed by the British services at the moment include the following. The R.A.F. has the air-to-air *Firestreak*, the surface-to-air *Bloodhound*, and the American i.r.b.m. *Thor*—see below. *Blue Steel* should go into service shortly. The R.N. has the surface-to-surface *Seaslug* and the surface-to-air *Sea Cat*. The Army has the ground-to-air *Thunderbird*, the American *Corporal* and *Little John* artillery weapons, and the *Malkara* anti-tank weapon. The i.r.b.m. *Blue Streak* and the tactical *Blue Water* are, of course, still under development.

R.A.F.'s operational Thors

The American Thor intermediate-range ballistic missile is now part of Bomber Command's armoury, and CONTROL was invited last month to R.A.F. Station Feltwell—not far from Ely—to see a typical site. Bomber Command have sixty Thors divided among four separate bases in East Anglia, of which Feltwell is one. Each base has five satellites (one of which is situated on the base) and there are three missiles per satellite, so that each Thor complex consists of fifteen missiles. Apart from Feltwell, no other base was mentioned, although a reference to 'the Driffield complex' passed without comment.

The Thor i.r.b.m.—originally the SM-75—was built by Douglas Aircraft to the requirements of the U.S.A.F., and its history is extremely chequered, although CONTROL understands that it is now as near perfection as any missile of its type. The first five experimental firings were failures, but the



PLENTY OF ROOM AT THE BERKELEY. The main control room at the C.E.G.B.'s Berkeley, Glos., nuclear power station. Three engineers will control the entire plant from this room. The panels at the rear are concerned with controlling and monitoring the water tube boilers—eight to each of the two reactors. The console controls and monitors the reactor plant. Incidentally, the C.E.G.B. is setting up a research and training establishment at Berkeley so doubtless the students will find this roomy control centre invaluable

sixth, on September 20, 1957, accomplished a successful 1300-mile flight. By January 1959, 24 R. & D. Thors had been fired, of which ten were successful, and from February 1959 a further 22 R. & D. missiles had been fired, twenty of which were successful. This is quite apart from some twenty Thors used in one form or another in the U.S. Space Programme.

As part of their training, R.A.F. crews have launched eleven Thors so far, and nine of these have been successful. CONTROL understands that the R.A.F. think highly of the weapon and have no doubt as to its efficacy in action. It appears that the Americans were most impressed by the R.A.F.'s handling of the missile; but this is to be expected, of course, for they are the only operational user of this 1500 nautical-mile-range weapon. The American launchings are apt to appear somewhat chaotic, not only because their firings are for research and development, but also because many civil establishments look upon the Thor as an ideal carrier for complex instrumentation of one form or another. The R.A.F., on the other hand, are interested in the Thor as a weapon only, and therefore their firings are purely military.

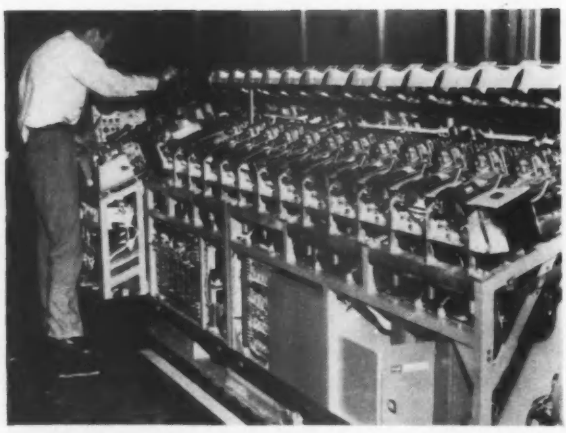
Thor is 65 ft long, 8 ft in diameter and has an all-up weight of 110,000 lb, 98,500 lb of which is due to the fuel (a jet-engine-type kerosene, with liquid oxygen as the oxidant). The missile is propelled by a Rocketdyne MB-2 liquid-propellant motor, which burns for just under three minutes, and is precisely controlled by two small Rocketdyne vernier motors. For about 1¾ minutes after launch, the missile's automatic pilot is programme-controlled, thence for a further minute an intertial system (by A.C. Spark Plug—the Electronics Division of General Motors) controls the flight path until the motors cut off. The nose cone, with the nuclear warhead, separates from the main body of the missile at a height and speed dependent upon the distance of the target from the launching point. The warhead cannot become armed unless the missile is in the proper ballistic trajectory, so any fear of destroying the wrong target would appear to be unfounded.

The nuclear warhead is under the strict control of the American authorities, and it would appear to be impossible for the British authorities to use it without active American consent. Each squadron of three Thors has its American 'authentication officer' who, presumably, carries out this 'authentication' duty. On the other hand, he could hardly launch global war without using the R.A.F.-controlled missiles.

The count-down for Thor nominally takes fifteen-minutes—or considerably less. However, as R.A.F. Bomber Command will fire only on instructions from the Anglo-American political chiefs, and the U.S. authentication officer has to contend with his own lines of communication to the American Strategic Air Command, the weapon is obviously a 'deterrent' only—it can never be used.

The maintenance problem for sixty Thors is obviously difficult, although the R.A.F. appear to have overcome it. They describe it as more difficult than maintaining a Canberra aircraft, and less difficult than maintaining a V-bomber. Various new R.A.F. trade groups have been formed to maintain Thor. The senior trade is usually Missile Fitter (Systems), and, as the title implies, such a technician is an overall systems man, although his previous background—electrical or mechanical—is taken into account. Other Missile Fitter trades include, Test Equipment, Guidance, Control and Propellant.

All in all, we were impressed by the workmanlike and efficient manner in which the R.A.F. have tackled the problems of their first ballistic missile.



LLOYDS RECOGNIZE MAGNETIC CHARACTERS
Lloyds Bank have ordered the Burroughs document sorter, shown here under test at Burroughs Plymouth Division. Capable of sorting documents of mixed sizes at speeds up to 1560 per minute, the machine reads characters printed with magnetic ink on cheques and other documents

BUSINESS

E.M.I. bid for Simon

Following E.M.I.'s unsuccessful bid for Lancashire Dynamo (Metal Industries won the auction — see these columns, last month), this leading electronics firm continues to seek a firmer foothold in general engineering. Their latest—and it appears more determined move is to bid £M16 for Henry Simon, a joint parent with Simon-Carves of a number of firms known as the Simon Engineering Group. The Group are probably best known as food engineers, their interest in flour milling going back many years.

There are a number of oddities about this move. E.M.I.'s Chairman, Sir Joseph Lockwood, is an old Simon man of long standing and is still a director of Henry Simon. The situation is further complicated by the fact that Henry Simon are on the verge of merging with Simon-Carves, Henry Simon have a strong financial interest in Simon-Carves, and it is possible that the reverse also holds.

E.M.I.'s reasons for wishing to take over Henry Simon are not, however, hard to surmise. The company is deeply immersed in autocontrol and automation—machine tool control, analogue and digital computers, electronic weighing devices, the Robotug automatically-controlled truck and so forth—but is weaker in the mechanical elements that go to make up a complete system. A merger with Simon Engineering would enable the joint concern to quote as system engineers of the highest calibre.

. . . and tie up with Fairbanks Whitney

An agreement has been reached between E.M.I. and the Fairbanks Whitney Corp. of New York (machine tools, diesel-electric locomotives, generators, aircraft and missile components etc.) whereby the latter will market most of E.M.I.'s electronic equipment in the U.S.A. Fairbanks Whitney will also manufacture certain E.M.I. equipment under licence. According to E.M.I. Electronics' Managing Director, Clifford Metcalfe, 'The flow of information and products will not be one way only, and certain equipment developed by the American company will be marketed in the U.K. and Europe by us. We are also going to study the possibility of a joint venture in the electronics field in the European Common Market.'

The first step is to be the installa-

tion of Emidec 1100 digital computers in the Beloit, Wisconsin, plant of Fairbanks Morse, and the Pratt & Whitney plant at West Hartford, Connecticut. E.M.I.'s Robotug driverless trolleys will also be installed at both plants.

For the record

The present situation in the aircraft industry—who controls whom—was described in *News Round-up* last month. Since then Westland Aircraft have taken over Fairey. As Westland had already acquired the helicopter interests of Saunders-Roe and Bristol, this latest acquisition makes them responsible for virtually all Britain's helicopter work. Westland will continue development of the Fairey Rotodyne.

It has also been reported that the Vickers-English Electric-Bristol group are to be known as the British Aircraft Corporation.

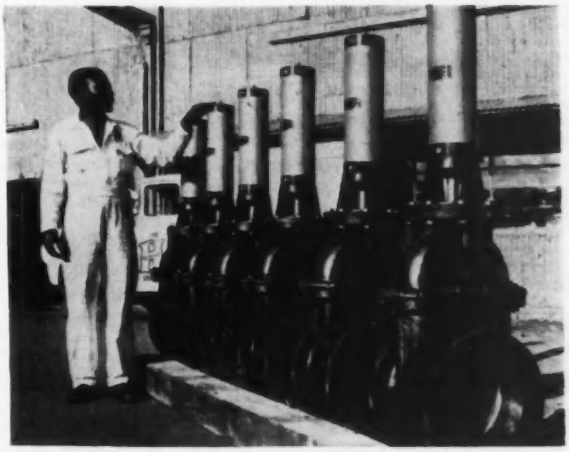
Incidentally, there is a surprising rumour to the effect that Handley Page may merge with the Hawker Siddeley-de Havilland group.

— NAVIGATION —

Autopilot for Airco DH.121

During the Duke of Edinburgh's recent visit to Smiths' Cheltenham factory, a film on the Multiplex autopilot was shown and the system was discussed by K. Fearnside, Director of Research and Engineering, Smiths Aviation Division. Mr. Fearnside said, 'For the purposes of automatic landing, the automatic control system must have a very small probability of failure during the landing operation and a similar stringent requirement exists during the high-speed cruise, particularly for the supersonic transport aircraft. The design target for an automatic landing system for civil use is a failure rate of less than one failure in ten million landings. The principle selected to achieve this target is that of multiplex operation. Each control channel in the system is divided into a number of sub-channels; each subchannel being independent and capable of controlling the aircraft satisfactorily in its own right. In normal operation all sub-channels work harmoniously together. If the channels are duplex (i.e., there are two sub-channels per control channel) a single failure cuts out the faulty channel in a manner which avoids disturbance of the flight path of the aircraft which is left in trim. In the case of a triplex system (i.e., one with three sub-channels per control channel) a single failure results in the faulty sub-channel being cut out leaving that channel still operating satisfactorily at duplex level. In both of these cases the gross disturbance of attitude and flight path often associated with failure in autopilots of current design is avoided, and in the triplex case a failure during the landing operation has no effect whatever on the flight path.

A practical design for production of an autopilot for the DH.121 is well advanced. This system will initially operate at duplex level, but is capable of extension to provide complete automatic landing without the introduction of untried components or expensive retro-modification. Looking further ahead, the system will be fully developed and proven in a form suitable for application to a supersonic transport at a time when this latter project is still in design stage, so that the design philosophy of such an aircraft can take full advantage of proven automatic control.'



These 10-in. bore gate valves at Durban Water Works are fitted with 5-in. air cylinders to provide remote opening and closing

— WATER —

Large valves controlled remotely

Gate valves of 10-in. and 14-in. bore are controlled remotely by pneumatic means at a new Water Works in Durban, South Africa. The system, which was developed by Holman Bros. and employs Maxam pneumatic cylinders, valves and associated control equipment, has overcome certain difficulties in achieving remote control and is said to provide rapid and accurate adjustment. The main valves are operated directly be pneumatic cylinders, which have replaced the normal hand wheels and rising stems. An extended stem has been attached to the valve member of each main unit, this forming the piston rod of the associated actuating cylinder. A visual indication of the correct operation of the main has been achieved by incorporating a second, small-diameter, rearward extension of the piston rod. This protrudes through a gland in the cylinder end-cap to provide the required signal. A 5-in. bore Maxam cylinder was used for the 10-in. valves and a 10-in. bore cylinder for the 14-in. units, both being controlled by standard valves.

— COMPONENTS —

Auto-assembly of transistors

Some two years ago, when the decision was made to 'transistorize' I.B.M. computers, it was apparent that large numbers of uniform, inexpensive transistors of high quality would be needed. The I.B.M. 7090, for example, contains over 50,000 transistors. With this in mind, I.B.M. have now developed an automatic system for assembling transistors at the rate of 1800 an hour. Said to operate five times as fast as semi-automatic methods, the new machine consists of nine units joined by conveyors. Tolerances as close as 0·0005 in. are claimed, as is greater uniformity of product than before. I.B.M. say this is the first automatic method of making *n-p-n* alloy junction transistors.

I.B.M.'s automatic system assembles transistors at the rate of 1800 an hour

–INTERNATIONAL–

British papers for I.F.A.C.

The Papers Panel of the British Conference on Automation and Computation have now submitted papers for the International Congress on Automatic Control which is to be held in Moscow from Monday, June 27 until Wednesday, July 6, 1960. The papers committee in Moscow have received more papers than they need and it is possible, therefore, that they may not accept all the British contributions.

B.C.A.C. have submitted the following papers:

Category 'A'

The application of Kolmogorov's equations to randomly disturbed control systems by J. F. Barret.
The optimization of a class of non-linear filters by J. K. Lubbock.
Relay control systems optimized for various performance criteria by A. T. Fuller.
Temperature rises in component parts for control systems by A. Tustin.
Multi-variable process control by H. K. Chatterjee.
The preparation of charts and tables for the optimization of automatic control systems with random inputs by J. F. Coales and P. Y. Lawrence.
The application of automatic control in the British Sugar Corporation Ltd. by T. Campbell-Macdonald and R. M. J. Withers.
An automatic machine for building bicycle wheels by A. V. Hemingway and R. L. Dressler.
Self-optimizing control mechanisms and some principles for more advanced learning machines by A. M. Andrew.
Developments and future possibilities of automatic control on the British grid system by W. Casson, F. Moran and H. F. R. Taylor.
Automatic control of long distance telephone calls dialled by subscribers by H. E. Francis.
The precision driving and absorption dynamometer, Part I—digital speed control, Part II—torque measurement by W. H. P. Leslie.
A study of interacting in a multi-loop control system by D. S. Mitchell and C. R. Webb.
Gain modulated control systems by J. C. West.
Automatic aids to improved supervisory control by C. A. Laws.
Techniques for the automation of analytical methods by D. A. Patient.
Time series and Z-transform methods of analysis of linear and non-linear control systems by A. J. O. Cruickshank.
Some steps towards automation in the steel industry by L. N. Bramley, S. S. Carlisle and R. B. Sims.
A quantitative design method for simple control systems by R. Jackson.
Approximate transient response calculation using some special sets of polynomials by O. P. D. Cutteridge.
Limitations due to noise, stability and component tolerance on the simulation of continuous physical systems by differential analysers by M. E. Fisher.
The stability of interacting control systems by A. Jeffrey.
Helixyn position control by D. J. Mynall.
Application of operational methods to sampling and interpolating systems by B. M. Brown.
The transient behaviour of multi-component distillation columns by H. H. Rosenbrock.

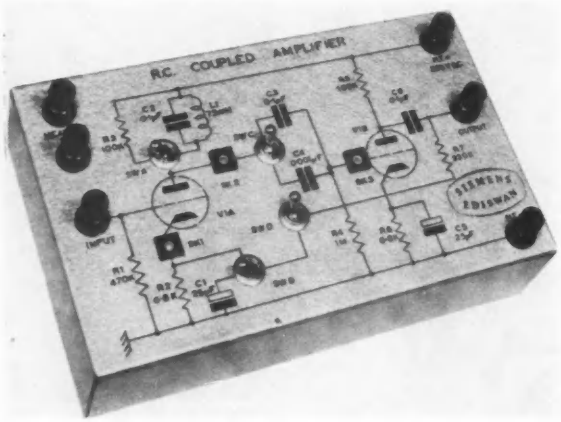
Category 'B'

An experimental control system with continuous automatic optimization by W. K. Taylor.
Control equipment for ship stabilization by J. Bell.
Theoretical and practical techniques applied to the design of a gas turbine engine governor by S. R. Tyler, R. Ruggles and D. B. Welbourne.
The parameter estimation problem by J. H. Westcott.

Details of the Congress are available from:

(a) The Organizing Committee of the U.S.S.R. National Committee for Automatic Control, Kalanchevskaja ul. 15-a, Moscow 1-53, U.S.S.R.

(b) The Honorary Secretary of I.F.A.C., Dr.-Ing. G. Ruppel VDI, 79 Prinz-Georgstrasse, Düsseldorf, Germany.



ELECTRONICS IN PRINT. An r.c.-coupled amplifier, one of the practical aids to the teaching of basic electronics theory which the Special Products Department of A.E.I. Radio and Electronic Components Division has developed in collaboration with Northampton Polytechnic. This unit costs £8

IN BRIEF

James Gordon are to hold a private exhibition of their instrumentation and controls for boilers, furnaces etc., at the Lion Hotel, Warrington from April 5–7, 1960. Details: James Gordon & Co. Ltd., Dalston Gardens, Stanmore, Middx.

Blood pressure follower (Winston Green), described in 'Control in Action,' November 1959, has been ordered in quantity (£12,000) by American hospitals.

Ferranti Pegasus II has been successfully experimented with by Martins Bank. Since January 1, one Martins branch has carried out current-account book-keeping including the production of statements for customers.

Data-processing standards. B.S. 3174: 1959 'Alpha-numeric punching codes for data-processing cards' is the first of a series of such standards to be published by the B.S.I.

Silicon of high purity is to be produced in Britain by Monsanto following an agreement with German Siemens.

Second Electronic Computer Exhibition and Symposium is to be held at Olympia, London, from October 4–12, 1961. Details: D. C. Scoones, Esq., Peat, Marwick & Mitchell & Co., 94–98 Petty France, London, S.W.1.

Swedish data processing equipment, the Wegematic 1000, by ABN-bolagen, has been shipped to Gevaert Photo-Producten N.V., Antwerp. This is the first Swedish-built electronic computer.

Deciplex electronic computer by Southern Instruments has been installed at the Coatbridge Technical College, Lanarks.—the first Scottish Technical College to have a computer.

Midlands Instrumentation Exhibition and lecture programme organized by A. M. Lock & Co. Ltd. (Newborough Road, Shirley, Solihull; telephone: Shirley 5703) will be held from March 22–25 at Bennett Hall, Central Y.M.C.A., Snow Hill, Birmingham, 4. Equipment from W. G. Pye, A. M. Lock, Evens Electroselenium, Elop Moisture Meters, Elcontrol, Telequipment, Stonebridge Electrical, Dr. W. Ingold (Zürich), Southern Instruments and Cossor Instruments, will be displayed.

Telemechanics Ltd. have moved to Brokenford Lane, Totton, Southampton; telephone: Southampton 3666.

Tektronix oscilloscopes—handled in the U.K. by Livingston Laboratories—have been reduced in cost some 3%. This is due to reduced freight charges consequent upon assembly in Guernsey. As an American import, Tektronix equipment is subject to import duty, and manufacture in Guernsey entails a request for Commonwealth Preference before duty-free importation into the U.K. is possible. Livingston Laboratories hope to make a further statement shortly.

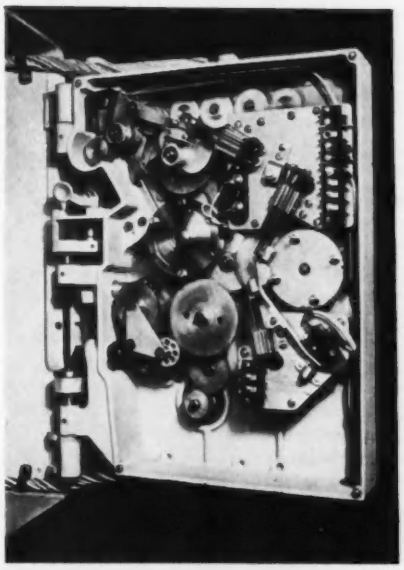
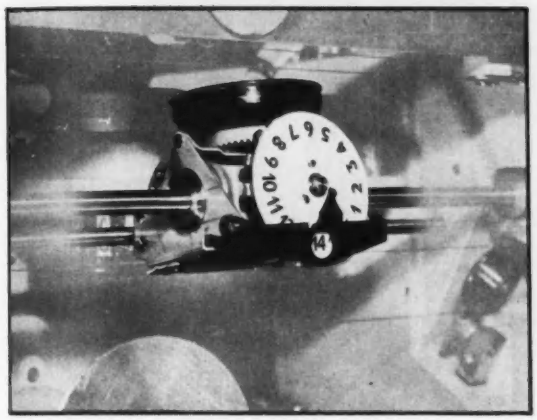


Chart-drive gear train and multi-point mechanism

This new *mark 3* electronic *multelec* recorder—



Multi-point printing mechanism with self-lubricating pen-carriage unit

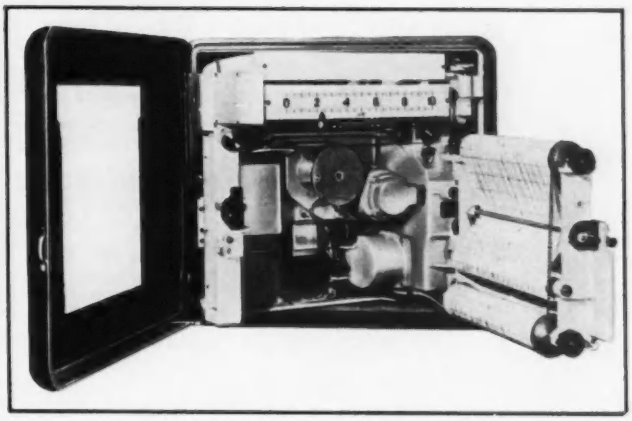
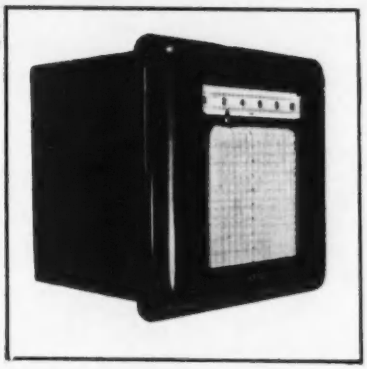


Chart frame swung away for ready access to main-frame components



Mark 3 Multelec recorder

—uses the same system and components as those in the electronic circular-chart recorder in the KENT *Commander* range. It retains, however, the same easy-to-read strip-chart (10 in. width) used in the *Mark* 2 *Multelec* instrument. The *Mark* 3 is available for the measurement of such variables as temperature, oxygen percentage, millivoltage, reactor power level, and—for certain applications—*Mark* 30 automatic control is included.

Outstanding features include :

- All-mains operation—no batteries; no standard cell
- Availability in single-, 2-, 3-, 4-, 6-, 8-, 12- and 16-point form
- 2-second full-scale travel
- High-speed, deadbeat balancing on both a.c. and d.c. inputs
- Wide choice of chart speeds, from ½ in./hour to 4 in./minute
- High-gain amplifier, with synchronous converter having extremely low drift
- Multi-point printing intervals of 5, 10 or 20 seconds, depending on application
- **Mark 30** Series air-operated automatic control is provided when required (single-, 2-, or 3-term); also electric on/off control

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New for Control

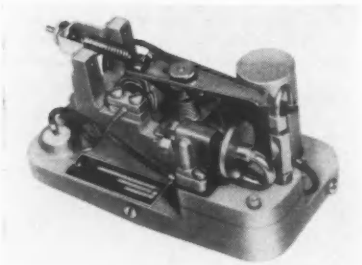
A monthly review of system components and instruments

TEMPERATURE TRANSMITTER

pneumatic output

The actuating element of a temperature transmitter is the Bourdon spring of a mercury-filled system, the spring moving a simple force beam which eliminates compression springs or balance weights.

The Sensaire converts measured temperature into a proportional 3–15 lb/in² output pressure, and due to the use of a small bulb has a rapid response-speed. Range spans are 50, 100, 200 or 400°F,



Accurate, sensitive

or 25, 50, 100 or 200°C, and calibration accuracy is stated to be within 1% below 550°F; maximum continuous over-range temperature is in the order of 100% above upper range-limit.

A derivative-response adjustment-unit is available, which may be used when a very fast response is required. Made by Taylor Controls, the Sensaire will operate within an ambient range of −30 to +150°F.

Tick **No 501** on reply card

MULTI-BANK VALVE

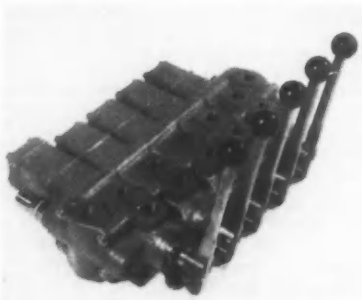
for hydraulic control

One of the main difficulties experienced in employing hydraulic control systems on mechanical handling equipment is the tendency for mechanisms already in use to be affected when other mechanisms controlled by the same circuit are brought into operation. A multi-bank valve designed for inclusion in such systems is claimed to permit the use of any number of valves in the bank, individually or simultaneously, without load-drop when controlling cylinders at lower than mains operational pressure. This has been achieved by incorporating a check valve in the valve body and positioning it in the pressure line between the valve spools. Specially formed valve-ports ensure that check valve and associated porting are of sufficient capacity to avoid the generation of heat under operational conditions.

Made by Joseph Young, these are available in a range of sizes with capacities from 15 to 45 gal/min at operating pressures up to 2000 lb/in². They can be used in any hydraulic control system.

Tick **No 502** on reply card

Will function up to 2000 lb/in²



OVERLOAD CUT-OUT

with snap-action element

Designed specifically for sub-fractional h.p. motors 1 in. in diameter and larger, a miniature over-temperature protector is equally suitable for small solenoids and transformers.

Responsive to both current and temperature, the protector is designed with a compensating heating element to ensure that the snap-acting, disk-type sensing element will follow closely the temperature changes of the component to be controlled. Protection levels are 150, 175 and 200°C. Maximum contact capacity is 5 amperes at 27 V d.c. or 120 V a.c., and the units conform to military specifications MIL-M-7967 and MIL-M-8609, or when mounted in equipment to MIL-E-5272.

The Texas Instrument's Klixon 5891 has no flanges or mounting projections, and the dimensions, 0·28 × 0·20 × 0·60 in., are kept to a minimum by using welded-on leads. Weight, excluding leads, is 1 g.

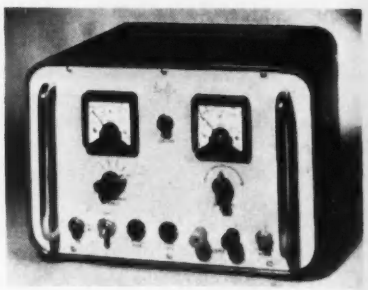
Tick **No 503** on reply card

POWER SUPPLIES

highly stabilized

Models are available in a series of high-stability transistor power-supplies covering the range 0·5 A at 0–10 V, and 1, 2, 6 or 10 A at 0–50 V. The output in each case is fully floating, and adjustment is made by coarse and fine controls with meters indicating output voltage. In order to obviate the effects of loss in connecting leads the 2, 6, and 10 A models have a pair of 'line loss' output terminals, which may be connected directly to the load so that true load voltage is indicated on the meter and stabilized by the control amplifier.

According to the makers, Metrix Instruments, a 'microsecond trigger' biases the supply down to zero volts in the event of an overload surge, and an augmenting relay system then cuts off the supply. Stability ratio with respect to



Indicates true load-voltage

mains is better than 2000:1, source impedance less than 0·005 Ω, and ripple is less than 0·5 mV peak-to-peak on all but the 10 A model, where it is 2 mV. Prices from £47 to £180.

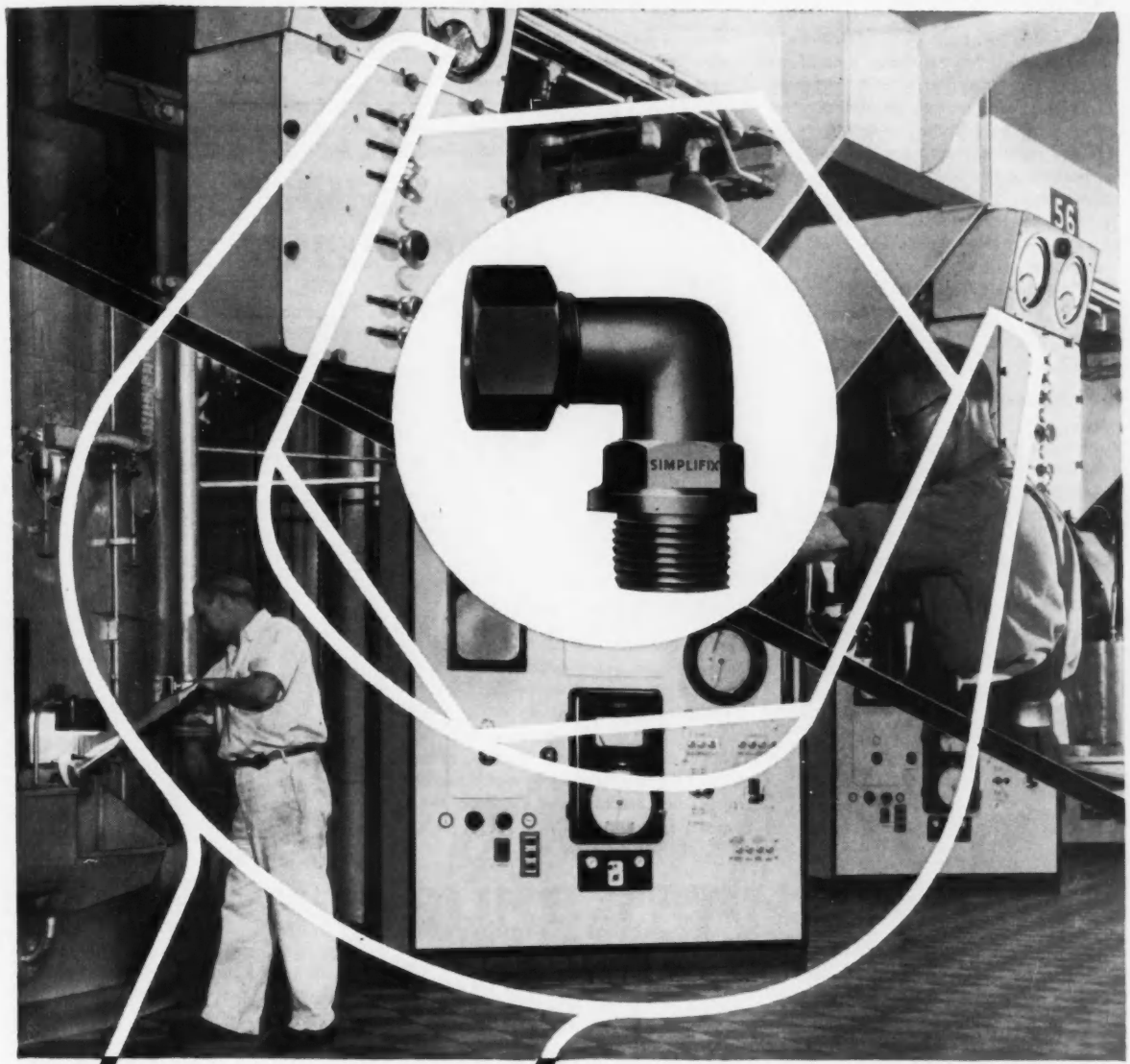
Tick **No 504** on reply card

CONTENTS GAUGE

for non-pressurized tanks

A pressure-bulb-type hydrostatic tank contents gauge will measure the head of liquid in most types of non-pressurized tank, wherever situated and regardless of size and height. Its indicator may be placed up to 250 ft from the tank to show by a dial and pointer (from 4 to 12 in. in diameter) either the depth of liquid or the tank contents. The gauge is completely self-operating and offers continuous indication.

It consists of two units, transmitter and indicator, together with suitable airline and connectors. The tank liquid fills the lower chamber of the transmitter unit, so pressing against the lower surface-area of a synthetic-rubber pressure-bulb. This pressure, the hydrostatic head of liquid in the tank, is transmitted through a small-bore air-line to the indicator. It is necessary to know the density of the fluid in order to calibrate the indicator in depth units and also the tank size and shape if readings are required in volume or mass units. The bulb is of such a shape that in operation it is similar to a



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Simplifix—the sure and simple compression coupling for copper pipe. Perfect joints with almost all kinds of tubing, including those with very thin walls. No work to do on the pipe. Simply tighten the nut —the anti-friction washer prevents pipe twisting. Manufactured since 1930, still the best. Millions in use. Made in sizes to suit tubing from $\frac{1}{8}$" to 2" O.D., in a wide range of interchangeable standard fittings. Non-standard fittings also made to order. Let us send you the Simplifix catalogue.

The illustrations show control panels and centrifugal machines at the Plaistow Wharf Sugar Refinery of Tate and Lyle Ltd., where large numbers of Simplifix couplings are used.

SIMPLIFIX

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rigid piston of large area sealed by a membrane of low stiffness around its edge. The transmitter unit, weighing 12 lb and with an overall diameter of 8¼ in., may be mounted externally with a short pipeline entering either the side or bottom of the tank to penetrate above sludge level.

Made by Firth Cleveland, the recommended working temperature at the transmitter is 65°C.

Tick **No 505** on reply card

D.C. AMPLIFIER

with variable gain

Two amplifiers are contained within this single unit, which is intended mainly for use in experimental work on system frequency and transient response, and as a unit for analogue computers.

One amplifier has a gain continuously variable between 1 and 20 by feedback adjustment. Its operating range is d.c. to 100 kc/s (±3 dB), and it has a balanced input stage to reduce drift effects. The other operates either at a gain of −1 for phase reversal (d.c. to 100 kc/s), or −150 (d.c. to 40 kc/s) for addition, integration, or function generation using external net-

'Two-in-one'

works. Maximum output in either case is ±50 V at ±2 mA.

The two amplifiers in the unit may be used independently, or connected in series to give a maximum gain of − 3000. Made by Feedback Ltd..

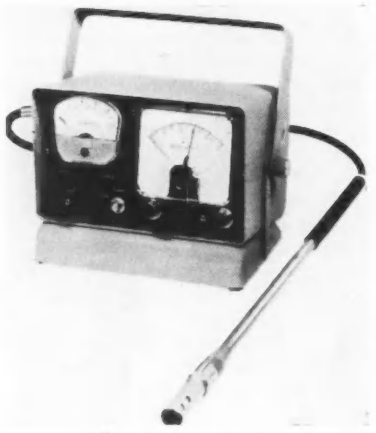
Tick **No 506** on reply card

GAS DETECTOR

with built-in alarm

Designed to give indication and alarm when gas concentrations reach unsafe levels, this unit may be operated as a portable instrument with probe-type element, or as fixed indicator/alarm with up to 100 ft of cable to detector element. Battery and battery-charger provide for portable power, and the unit may also be operated directly from 110 V a.c.

The indicator meter is calibrated in percentage of lower explosion-limit of



Mains-operated or portable

gas in question. An adjustable meter trip provides an alarm circuit for a built-in buzzer alarm, auxiliary contacts are provided for external alarm or shut-down circuits, and an adjustable current-meter allows approximate classification of individual gas constituents in many gas mixtures. Manufactured by Houston Instruments, U.S.A.

Tick **No 507** on reply card

PYROMETER

for exhaust-gas temperature

A pyrometer for measuring diesel-engine exhaust-gas temperatures at the cylinder outlets or in the exhaust manifold has been developed by Savage and Parsons. The instrument comprises up to eight iron/constantan thermocouples, in stainless steel sleeves, and a moving-coil meter which can be mounted on the instrument panel.

The thermocouples may be fitted through an entry port in the exhaust-manifold, and each thermocouple is connected to the meter, which has eight pairs of terminals moulded into its back, enabling up to eight separate positions to be measured. A nine-position selector-switch on the front of the meter allows the operator to select each thermocouple in turn, and the temperature can be read directly off the dial.

A bi-metal strip incorporated in the meter automatically compensates for changes of ambient temperature once the zero has been set. The dial is scaled for temperature readings from 0–1600°F with the position of maximum accuracy at 1200°F, and the meter may be calibrated for any desired length of 22 s.w.g. lead from the thermocouples, up to 50 yd.

Tick **No 508** on reply card

FLAME PROTECTOR

with magnetic gas valve

A flame protection system is said by the makers to give rapid shut-off of gas in the event of flame failure.

The unit consists of three parts: a magnetic gas-valve; a pilot burner and sensing probes; and an amplifier. Upon establishment of the pilot flame a current flows between probe and earth, which is passed to the amplifier, the amplified signal holding the magnetic gas-valve open. For starting, the magnetic valve may be opened by a push-button. Flame failure, or short-circuiting of probe to earth, causes closure of the magnetic valve after a two-second delay.

The Perltronic 90 is made by Perl Controls.

Tick **No 509** on reply card

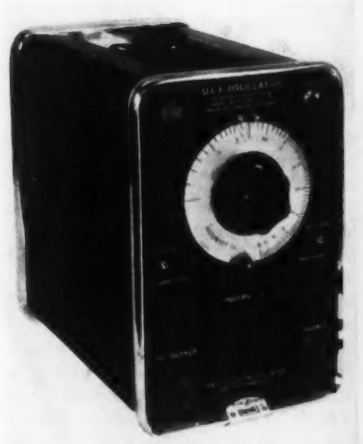
OSCILLATOR

for ultra-low frequencies

With output continuously variable over a frequency range 0·01 c/s to 1 kc/s by resistance-capacitance tuning, this oscillator incorporates a selective amplifier circuit with controlled positive feedback to maintain continuous oscillation. The feedback circuit includes a symmetrical diode limiter, the constant-amplitude rectangular wave from which is applied to the input of the amplifier. The sensitivity of the amplifier reduces the harmonic content of the output to negligible proportions.

The diode limiter also has the advantage of providing amplitude control down to the lower limit of frequency. After a sudden transient (e.g. changing ranges) the amplitude of oscillation is stabilized within about three cycles. This rapid response, together with the ability to tune continuously from 0·01 c/s to 1 kc/s, makes the oscillator suitable for

Fundamental and quadrature outputs



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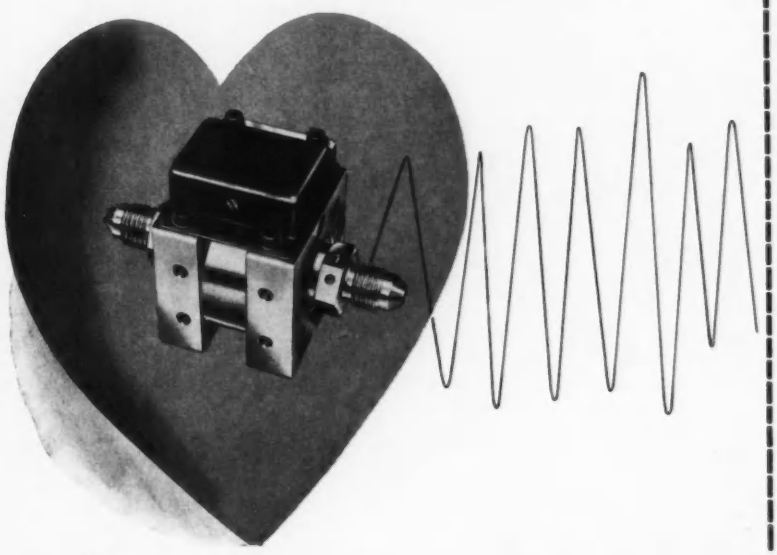

Output available for:

Galvanometer Recorders
0 – ± 4 mA, 500 ohm

Chart Recorders
0 – 200 mV

Magnetic Tape Recorders
0 – ± 3 V

Telemetering Preset
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SE 70	$\frac{7}{8}$" x 1"	0 – ± 2 p.s.i. to 0 – ± 400 p.s.i.
SE 50	1$\frac{1}{2}$" x 1$\frac{1}{8}$"	0 – ± 5 p.s.i. to 0 – ± 2,000 p.s.i.
SE 65	2" x 1$\frac{1}{2}$"	0 – ± 2,000 p.s.i. to 0 – ± 6,000 p.s.i.

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Tick **No 87** on reply card for further details

checking the performance of low-frequency recorders.

At the frequency of oscillation, each of the two integrators gives a phase shift of very nearly 90°. A quadrature output is therefore available after the first integrator stage, which may be used for testing servo systems. The output level of the 0° output is continuously variable up to a maximum of 15 V into a minimum load of 10 kΩ, output being constant within ± 4% over the entire frequency range. The distortion is less than 0·5% from 20 c/s to 1 kc/s. Hum and noise are less than 0·1%. The 90° output has a phase accuracy of 90° ± 0·5° (lagging) referred to the 0° output measured at 400 c/s.

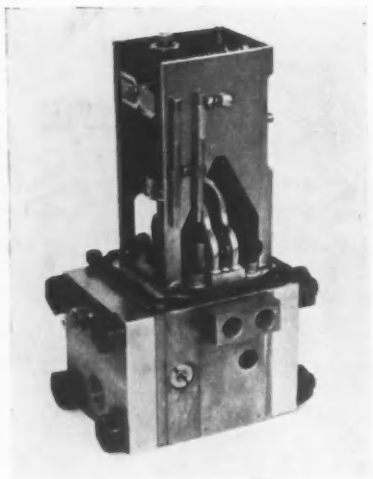
The type 445, by Dawe Instruments, has overall dimensions of 8¼ × 13 × 12¼ in. with a net weight of 19½ lb. Power consumption is about 50 W.

Tick **No 510** on reply card

PRESSURE TRANSMITTER

pneumatic output

A transmitter converting differential pressure to a proportional pneumatic output signal of 3–15 lb/in² is of the force bal-



Accuracy within 1% f.s.d.

ance type with continuously adjustable damping. The range is adjustable from 0–20 in. to 0–200 in. water gauge; inversion of the range-adjusting nut increases this to 0–30 in. to 0–300 in. Accuracy is claimed to be 1% of full scale.

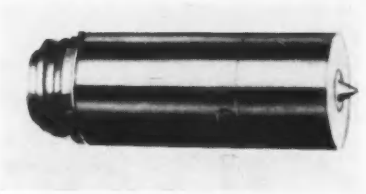
The body of the Fischer and Porter model 1465 is stainless steel, working parts being enclosed in a Fibreglass cover. It is the British version of their American associates' model 10 A 1460.

Tick **No 511** on reply card

MAGNETIC PICK-UP

constant-amplitude output

A magnetic transducer, with an output wave-form suitable for most types of high-speed electronic counting equipment, incorporates a transistorized trigger-circuit which operates from supply voltages between 3 and 25 V, and eliminates the need for screened cables, step-



Speeds from 10–10,000 rev/min

up transformers and shaping circuits in the associated electronic equipment.

Movement of any ferrous object adjacent to the tip of the pole-piece generates a constant-amplitude constant rise-time square wave. When used with shaft-mounted toothed wheels this pick-up enables accurate revolution counting and shaft-speed measurements to be carried out over a range of speeds from less than 10 to more than 10,000 rev/min.

Made by Pentechnique, this totally enclosed pick-up will operate in ambient temperatures up to 50°C.

Tick **No 512** on reply card

POWER SUPPLY

rapid overload protection

A transistorized power-supply, developed for computers, has five outputs ± 15 V at 10 A; ±6 V at 5 A; and 48 V at 1 A.

A fast-acting overload device is claimed to cut off all outputs if current drawn exceeds a predetermined value, and manufacturer's figures of 0·2% and less than 3 mV are quoted for line and load regulation and ripple respectively. Made by Invar Electronics (U.S.A.) the unit measures 7¼ × 17 × 13 in.

Tick **No 513** on reply card

MINIATURE POTENTIOMETER

aluminium cased

Said by the makers to be the smallest spindle-operated model in production, the type L is 0·5 in. in diameter, and has a rating of 0·25 W.

There are two tracks, a carbon (resistive) outer, and a silver-loaded (conductive) inner, bridged by a single insulated brush. The maximum working voltage is 350 V, and it will operate between −55 and +85°C. Available from Plessey, resistance range is 1 kΩ to 2·5 MΩ, linear law only.

Tick **No 514** on reply card

Small but robust

QUICK LOOKS

Silicon resistors with values extending from 68 Ω to 1·8 kΩ (± 10%) are now made as standard items by Texas Instruments.

The Sensistor silicon resistor, a temperature compensating and sensing device, features a large positive temperature-coefficient of 0·7%/°C and a constant predictable rate of resistance-change with temperature. These features, it is claimed, make this resistor ideal for temperature compensation and sensing from −50 to +200°C in very-high-frequency circuitry.

They are now available in three types: the TM 1/4 and TM 1/8 axial-lead moulded units, and the TC 1/8 in a standard round welded case.

Tick **No 515** on reply card

Described by the manufacturers as a 'transistorized analogue frequency meter', the TSA 501 covers a range of 3 c/s to 300 kc/s in ten steps, each range expandable by a factor of three or ten.

Made by Venner Electronics, this instrument will accept inputs of amplitude between 20 mV and 250 V r.m.s. for sine waves, or 0·5 to 500 V peak for pulse-wave-form. Operated from a 12 V internal battery, or 50 c/s 200–250 V mains, the input impedance is 250 kΩ shunted by 50 pF.

Tick **No 516** on reply card

Measurement of background radiation is continuously recorded by a portable instrument powered by a car-battery. It consists of an 18-in. long ionization chamber mounted vertically on an hermetically-sealed case containing the electrometer circuitry and a clockwork recorder.

The makers, Electronic Instruments, state that the Gammagraph has a zero stability better than 2% of full-scale for one month, and that the device will operate continuously for this period without maintenance or attention.

Tick **No 517** on reply card

An inductance pressure-tranducer is of the retracted diaphragm type for use with an f.m. system. The makers state that it may be calibrated statically, but has a high frequency response, and is capable of withstanding 100% overload without damage. Linearity and hysteresis are better than ±1% of full range, and it should work up to 150°C without cooling. Said to be splash proof, and resistant to attack by corrosive atmospheres, the G300 is available from Southern In-

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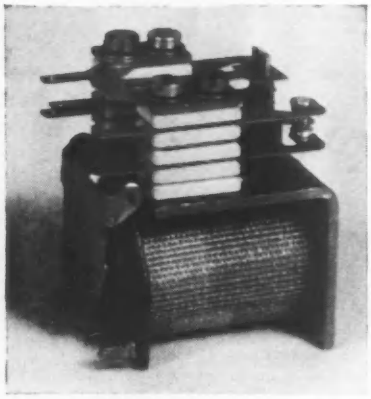
struments in pressure ranges from 0–10 to 0–10,000 lb/in², with mounting threads ⅛, ¼, ½ in. BSP, and 14 and 18 mm.
Tick **No 518** on reply card

A range of multiple barrelling-machines is available in three models: the 6/12 (basic 6-drum unit), 9/12 (basic 9-drum unit), and 12/2X (basic 12-drum unit).

The plastic barrels have a capacity of 0·25 ft³, and separate time-switches for each barrel control processing so that at the end of each time-cycle the cradle holding the appropriate barrel falls forward indicating completion of process.

Developed by Rolls-Royce, the Multi-Matic is marketed by Roto-Finish.
Tick **No 519** on reply card

These general purpose relays will operate a 4-pole change-over stack for 0·75 W d.c. or 5·0 VA a.c. input, and are available



in various contact formations. The 4-pole change-over will make or break 5 A at 30 V d.c. or 5 A at 230 V a.c. (non-inductive).

B. and R.'s M.01 (d.c.) and M.51 (a.c.) relays measure $1\frac{1}{2} \times 1\frac{1}{16} \times 1\frac{13}{16}$ in., and may be fitted with an integral transistor-amplifier for high sensitivity.
Tick **No 520** on reply card

A unit designed to detect 'tramp' iron in conveyor loads etc., may be made to operate a warning or control device.

The type TN, consisting of a search coil and control unit, is made by Metal Detection Ltd.
Tick **No 521** on reply card

The Unical decimal desk-calculator, Swiss designed, is now available in England from Kenneth Miles. It is claimed that the 99 table cards enable solution of simple products (up to 99 × 9999) to be found as quickly as by an electric calculator.
Tick **No 522** on reply card

A range of totally-enclosed fan-cooled motors claimed to be smaller and lighter than existing motors of similar type is announced by English Electric. The dimensions of the new motor are exactly the same as the type 'C' ventilated motor (British Standard 2960) and the two types are interchangeable. Features of these motors are an all cast-iron exterior with finger-proof cowls, a plastic non-corrosive external fan, and a weather-proof terminal box.

The range of outputs is covered by twelve frame sizes: 2-pole 1½–30 h.p.; 4-pole, 1–40 h.p.; 6-pole, ½–25 h.p.; 8-pole, ½–20 h.p. The motors can be wound for operation on any two- or three-phase supply up to 650 V at 50 to 60 c/s, and will give an average starting-torque of approximately 200% full-load torque with an average starting current of 700% full-load current when started direct-on-line.
Tick **No 523** on reply card

Where control of several stages of cooling and/or heating is required, multi-switch temperature-controls, with from two to five switches, are available from the Partlow Corporation (U.S.A.). Each of the five switches may be set independently at any point on the scale, and it is claimed that a typical example of this type will control a fall of from 100 to 10°F in 15 minutes with perfect linearity.
Tick **No 524** on reply card

A potentiometer, manufactured primarily for servo operation, is precision machined, and has ball-races fitted in the lid and base to ensure minimum end and side play on spindle, and low operating torque. The effective angle of resistance on standard models is 300°, and the maximum resistance is 200 kΩ on a card winding.

It is $1\frac{3}{16}$ in. in diameter with a depth of $1\frac{7}{32}$ in., and is made in 2 W or 4 W ratings by General Controls.
Tick **No 525** on reply card

Filters for compressed-air pipelines are available either for normal concentrations of water, oil-mist, or grit, or for virtually complete removal of oil- and water-mist where pure air is essential.

Made by Vokes to take ¼, ⅜, and ½ in. air lines, models with transparent bowls will withstand up to 150 lb/in², with metal bowls up to 250 lb/in².
Tick **No 526** on reply card

An hermetically sealed potentiometer designed to work within the range −40 to +70°C, is available from Plessey. Resistance range extends from 500Ω to 2·0 MΩ (linear or logarithmic), and maximum voltage across resistance is 500 V.
Tick **No 527** on reply card

A combination controller for seam or roller spot welding machines provides synchronous starting and stopping of welding-current, and time-control of each 'weld' and 'off' period. Heat control is by ignitron phase-shift.

The timing circuit uses Dekatron counting tubes, which are displayed to show the count in progress, and the timing-unit chassis is hinged to swing forward for easy servicing.

Made by British Federal, the HC/4-SS/1 will work from any 50-60 c/s supply between 350 and 520 V.
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An instrument for testing coils for shorted turns is available in either a mains or battery-operated model. Indication is provided by a green or red light showing good or faulty coils. Made by A.C. Industries, the standard model has a probe $2\frac{1}{2} \times \frac{5}{16}$ in. diameter.
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INDUSTRIAL PUBLICATIONS

Non-metal pumps for active fluids are described in a leaflet (*Lab Mail*) from Glencreston.
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Stepper motors and pulsed stepping devices are shown in a booklet from A. W. Haydon Co.
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Valves and cathode-ray tubes for industrial use are shown in the 1960 catalague of the M-O Valve Co.
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Gas-ratio controller. Comprehensive details are given in a leaflet published by Union Carbide International Co.
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Equipment for automation in analysis manufactured by Baird & Tatlock is shown in their brochure entitled *Analmatic News.*
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Flow-gauges and valves are two of the items described in a set of six data-sheets from Drallim Industries.
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Analogue computer units are described in a catalogue from Bruce Peebles & Co.
Tick **No 536** on reply card

The Weissenberg rheogoniometer is explained in a booklet by Farol Research Engineers.
Tick **No 537** on reply card

Polarographic equipment is featured in a catalogue from the Cambridge Instrument Co.
Tick **No 538** on reply card

Motors for cranes, hoist and lifts. A catalogue from the Lancashire Dynamo & Crypto Co.
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B.T.H. escort marine radar. Details are given in a new coloured brochure issued by Associated Electrical Industries.
Tick **No 540** on reply card

Brodie-Kent meters. A new booklet together with literature on some remote control equipment is published by Gilbarco.
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'A World of Meaning' is the title of a new 100 page book published by Smiths, dealing with all their engineering (and domestic) products.
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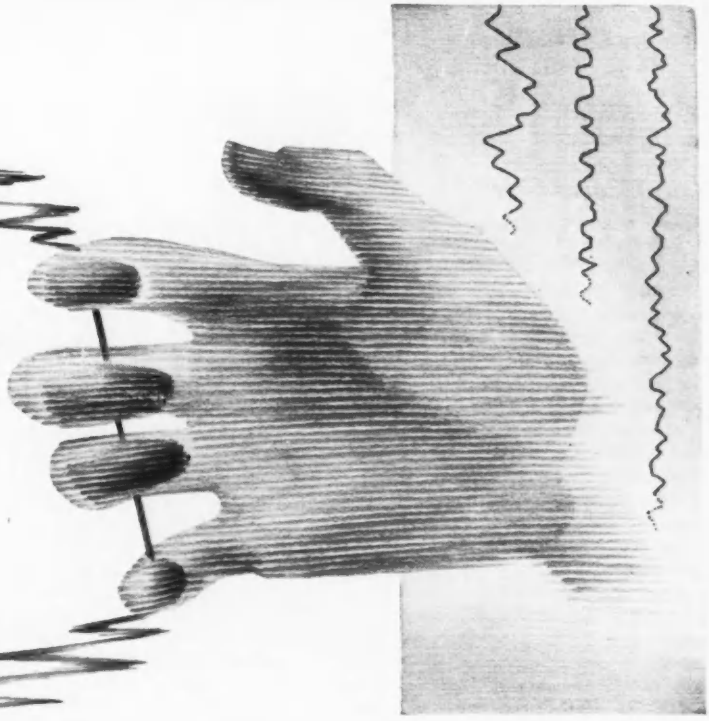
High-speed PEN RECORDERS



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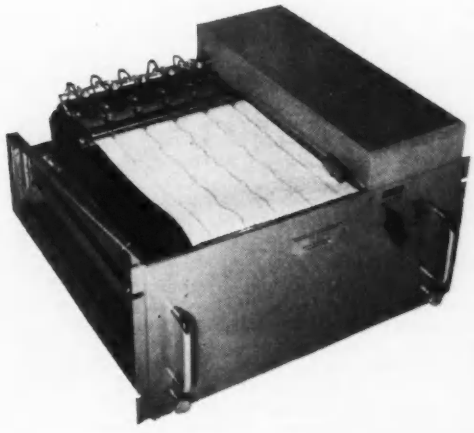

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Book Reviews

Amplifiers

Circuit Theory of Linear Noisy Networks *by* **H. Haus** *and* **R. Adler.** *Chapman & Hall. 1959. 79 pp. £1 16.*

This is a book for the specialist.

Recently there has been a great deal of interest aroused in parametric amplifiers because of their low-noise characteristics. The present book does not set out to provide a theoretical treatment of such devices, but it does set out to look for a rational approach to the characterization of amplifier spot-noise performance, and the general matrix methods developed are obviously capable of extension to deal with more complicated problems.

The problem of noise-performance optimization leads naturally to a search for the properties of linear noisy networks which are invariant under lossless network transformations. In the present volume these invariants are determined for multi-terminal pair networks and their physical interpretation in terms of a generalized 'available power' are presented. A canonical form is also developed which exhibits all the invariants in a particularly simple way. The authors then proceed to consider the special case of a linear two terminal pair amplifier, and show how to obtain a lower limit on its noise performance. The various ways of achieving this lower limit are then presented and discussed.

The book is only the second contribution of the Technology Press Research Monographs, which has as its objective making available research studies readily accessible to the libraries and the independent worker.

DENIS TAYLOR

Arcs

The Electric Arc *by* **J. M. Somerville.** *Methuen & Co.: London. John Wiley & Sons: New York. 150 pp. 12s 6d.*

While this monograph is not conventionally speaking a reference book—and Dr. Somerville makes some careful disclaimers to this effect in his preface—it is compact and comprehensive and may sometimes be used for reference. The five chapters are self-contained, and designed to give the non-specialist reader a clear physical picture of the phenomena. Among the matters dealt with are the properties of the arc column, electrode-column junctions, and the approach to the stable arc. There is an excellent bibliography with nearly 200 entries.

K. J. SPARE

Calculus

Operational Calculus *by* **Jan Mikusinski.** *Pergamon Press. 1959. 495 pp. £5*

It is a pleasure to be able to recommend this book as a very readable and well-written text on operational calculus. One of the Pergamon Press series on pure and applied mathematics, this volume by Professor Mikusinski has been translated from the second Polish edition. German and Russian editions having previously appeared. Occasional phrases betray this book as being a translation: the use of 'voltage pulsation' for angular frequency and 'cathode-ray tube' where valve (or vacuum tube) had been intended are examples. Otherwise the translation is excellent.

For a rather large investment one obtains an ample return in this book, which contains much original material previously appearing only in foreign-language journals. Using the definition of convolution as a basis, operational calculus is developed in the four main sections of the book, which deal with operational algebra, sequences and series of operators, operational differential calculus and linear differential equations with constant operational coefficients. Chapters are devoted to such applications as electric circuit theory, vibrations of a string and the equations of telegraphy. An extensive appendix deals in further detail with many aspects of the material covered in the main section of the book. Operational formulae and tables of Gamma, Bessel and Error functions are included in the section on formulae and tables. A welcome aspect of this book are the many worked examples and the large number of problems for which answers are given. A number of misprints occur, but of those noticed by the reviewer none would mislead the reasonably knowledgeable reader. One will look in vain for a table of contents at the front of the book. It appears at the end, followed, where one could very easily overlook it, by a list of misprints.

This is not a book for the average engineer. Control engineers, familiar as they mostly are with the Laplace transform, are not likely to change to the methods described. The mathematically inclined person will, however, find this a stimulating book to borrow from a library. The outstandingly logical and clear writing will be of considerable help to him in learning to use the novel methods employed by the author.

R. J. KAVANAGH

Operations

Operations Research Methods and Problems *by* **M. Sasieni, A. Yaspan** *and* **L. Friedman.** *Chapman & Hall: London. John Wiley: New York. 1959. 316 pp. £4 2s.*

Much of the subject matter of this American book arose out of a problems course in operations research, designed as a companion course to the general methods course offered at Case Institute of Technology. A reader is assumed to have a working knowledge of the differential and integral calculus, should be familiar with the extreme values of a function of one or more variables, interpretation of a single or multiple integral as the limit of a sum, and the calculus of finite differences (there is a short explanatory appendix on this subject). A little knowledge of statistics is also necessary.

The book is primarily addressed to would-be specialists in the field, but could prove of interest to control engineers who may wish to see if the mathematical treatment of problems in, for example, sampling, equipment replacement, waiting times, competitive strategies, allocation of available resources and processing each of n jobs through m machines, could help them in solving some of their own design problems.

The book is excellently produced and the type is most readable.

L. LANDON GOODMAN

Literature Received

Electronic Computers—Principles and Applications *by* **T. E. Ivall.** *Iliffe & Sons, London. Philosophical Library, New York. 1959. 263 pp. £1 5s* ★ 701

Proceedings of an International Symposium on the Theory of Switching Parts I & II. *Harvard University Press. London: Oxford University Press. 1959. 648 pp. £6 per set* ★ 702

Trace Techniques using the K1000 Cathode Ray Polarograph *by* **J. Hetman.** *Southern Instruments Ltd. 1959. 48 pp. £1 5s* ★ 703

Instrumentation and Computation in Process Development and Plant Design. *Institution of Chemical Engineers. 1959. 175 pp. £4* ★ 704

Automating the Manufacturing Process *by* **George F. Hawley.** *Reinhold Publishing Co. 1959. 147 pp. £2* ★ 705

Similarity and Dimensional Methods in Mechanics *by* **L. I. Sedov.** *Cleaver-Hume Press, London, for Infosearch. 1959. 363 pp. £5 5s* ★ 706

Autocontrol Experiments on Dido using Discontinuous Feedback *by* **L. A. J. Lawrence.** *A. E. E. Winfrith. 1959. 42 pp. 6s* ★ 707

Diode Response and Time Derivative of Response to an Exponentially Increasing Input Current *by* **J. D. Cummins.** *A. E. E. Winfrith. 1959. 12 pp. 2s 6d* ★ 708

Electrical Noise: Fundamentals & Physical Mechanism *by* **Dr. D. A. Bell.** *D. van Nostrand Co. Ltd. 1960. 342 pp. £2 10s* ★ 709

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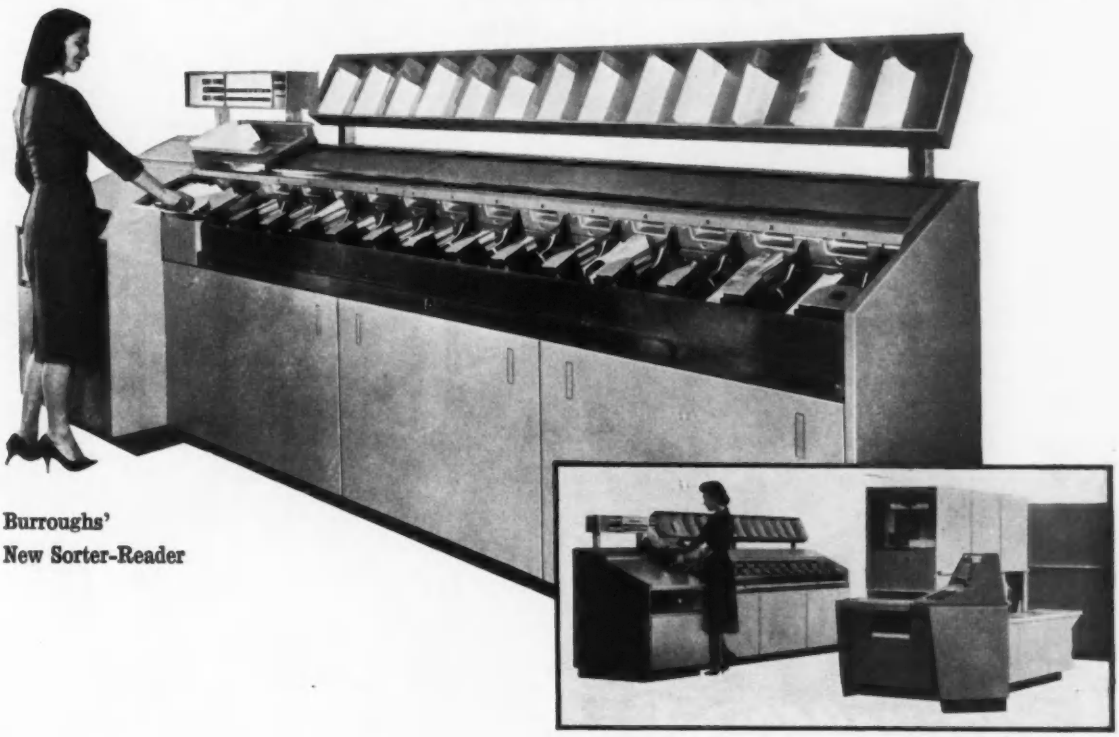

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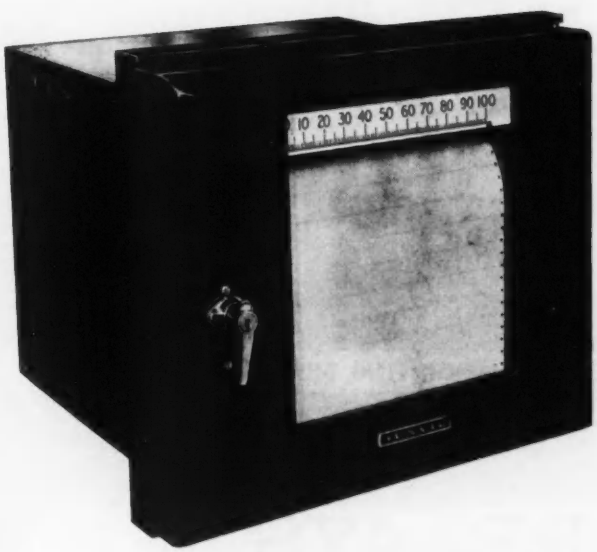

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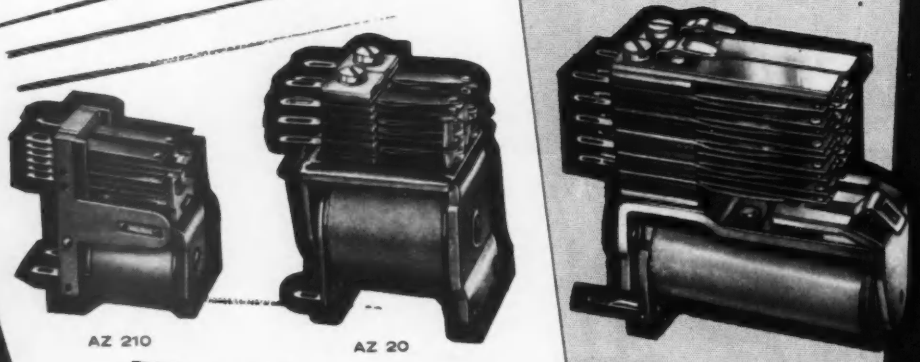

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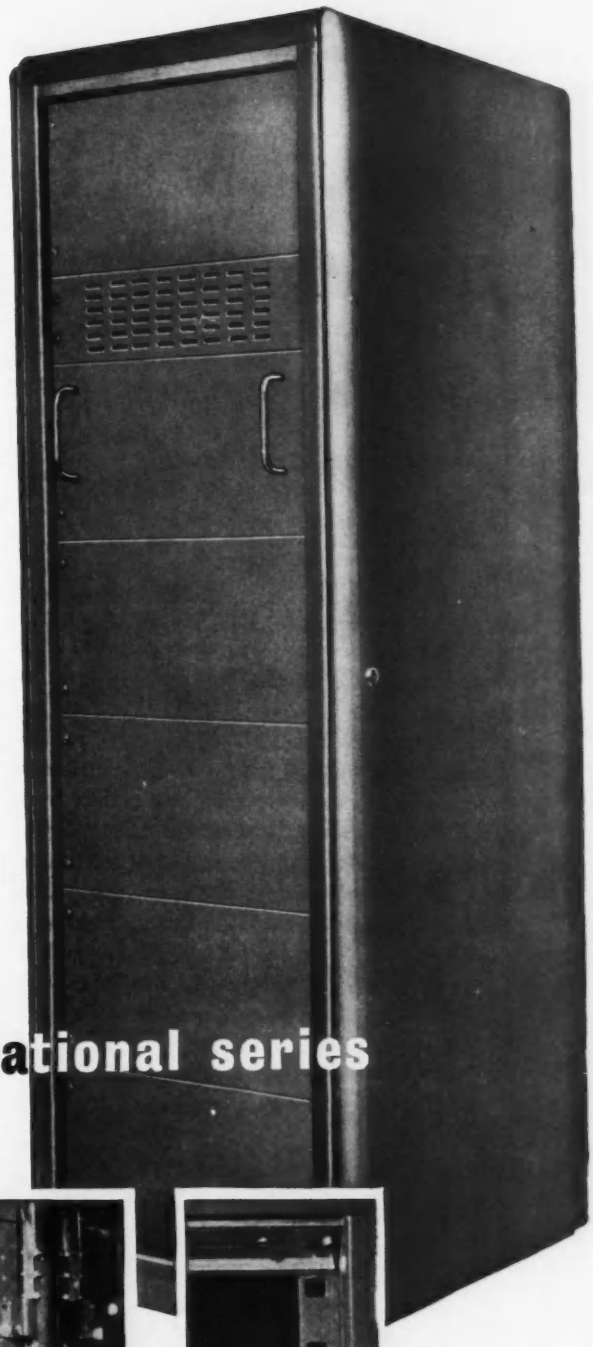

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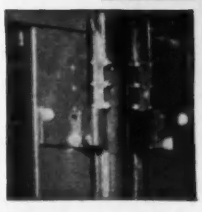

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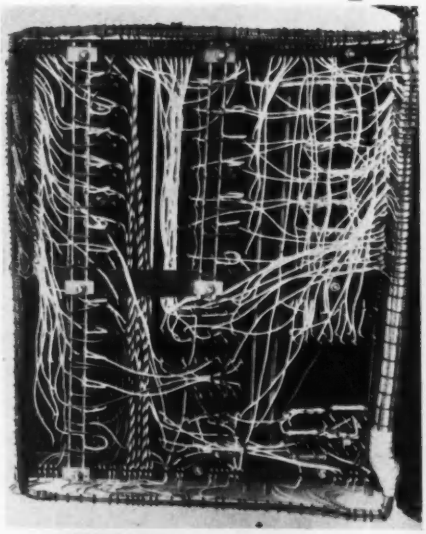

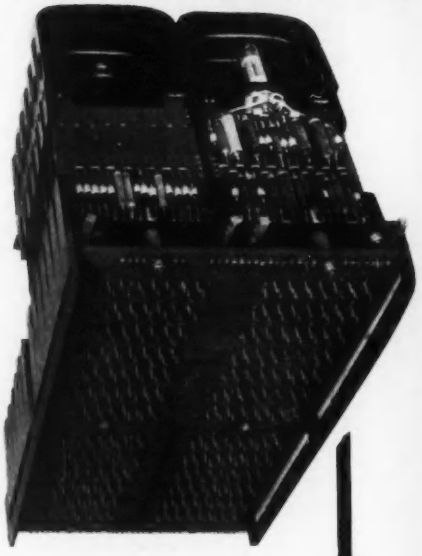

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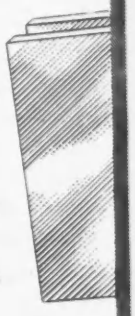

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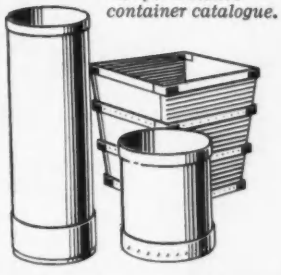

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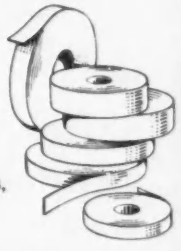

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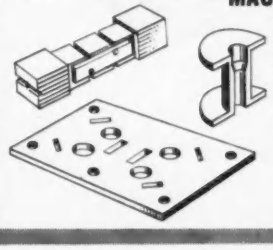

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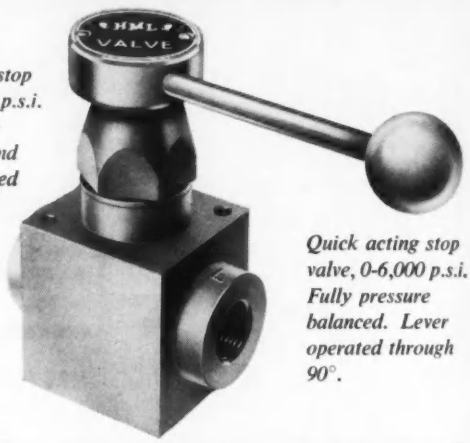
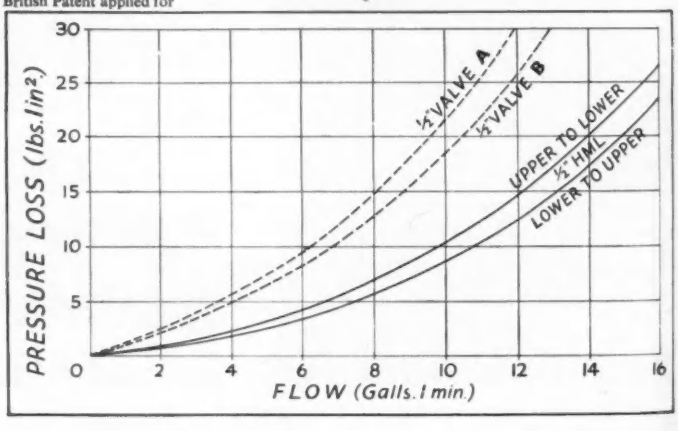


Quick acting stop valve, 0-6,000 p.s.i. Fully pressure balanced. Lever operated through 90°.

British Patent applied for

Tests prove that H.M.L. valves give lower pressure losses with flow in either direction. Valve body design allows 25% increase over pipe flow area. (Test fluid D.T.D. 585, kinematic viscosity during tests, 22 centistokes.)



HML

H.M.L. (ENGINEERING) LTD., 466-490, EDGWARE ROAD, LONDON, W.2. **Tel: PADdington 0022**

Works: HARPERS YARD, ST. JOHN'S ROAD, ISLEWORTH, MIDDLESEX. Tel: ISLeworth 3011

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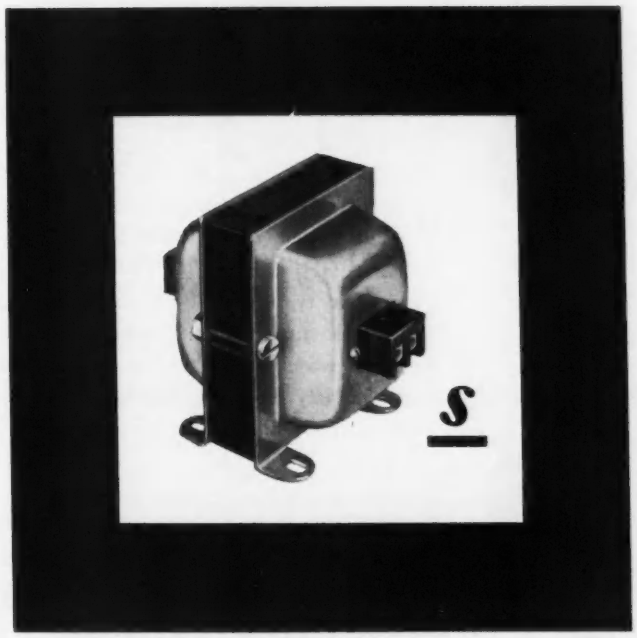

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CP4

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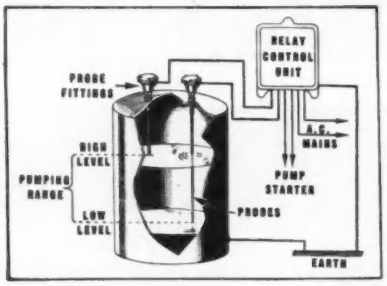

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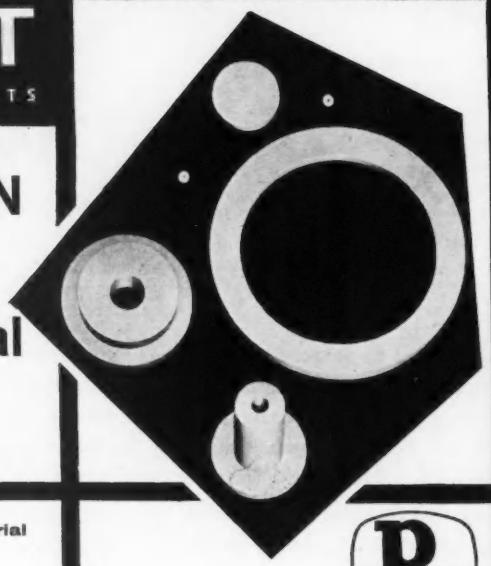

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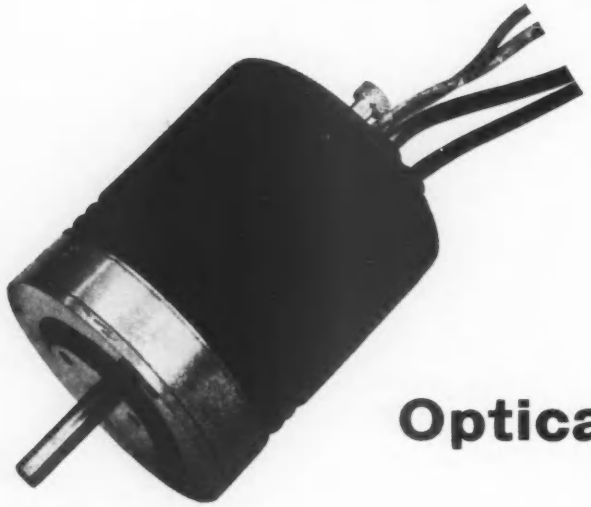

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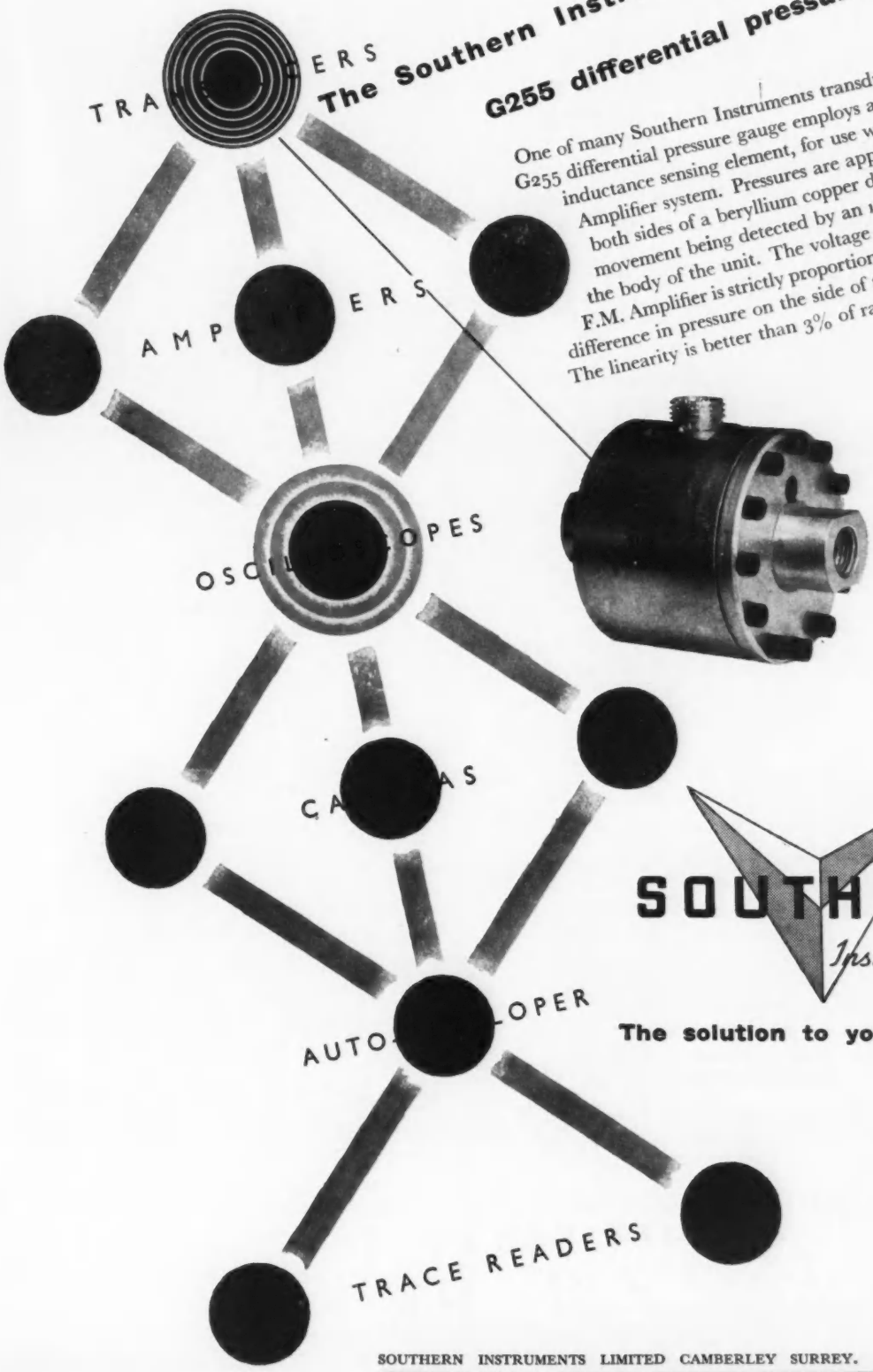

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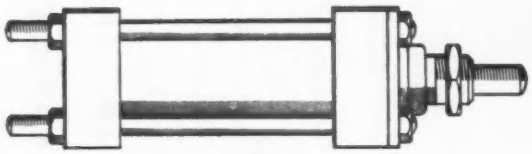

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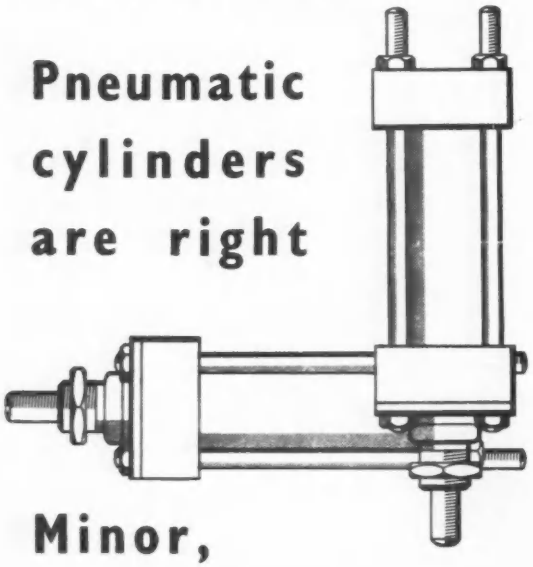

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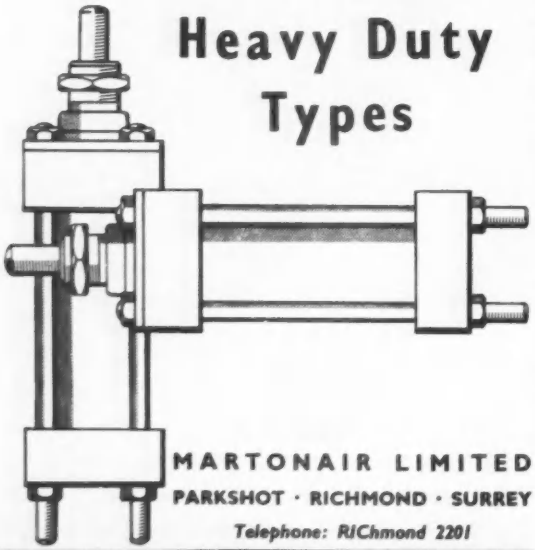

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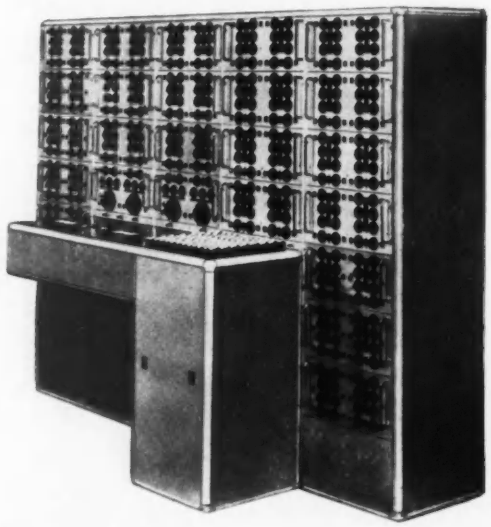

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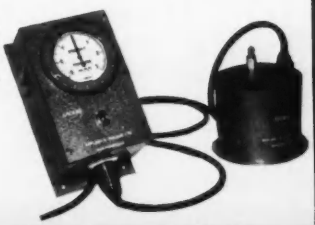

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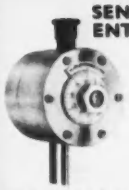

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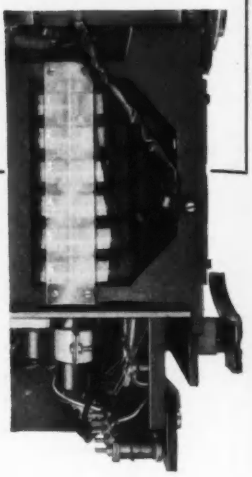

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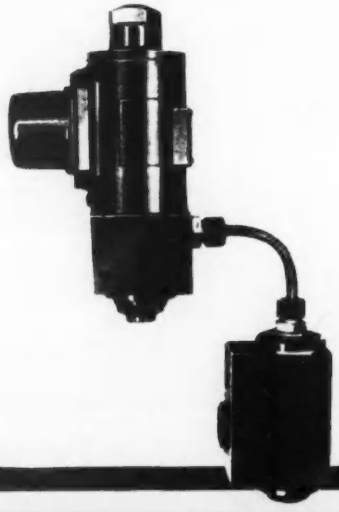

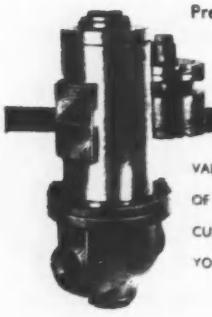

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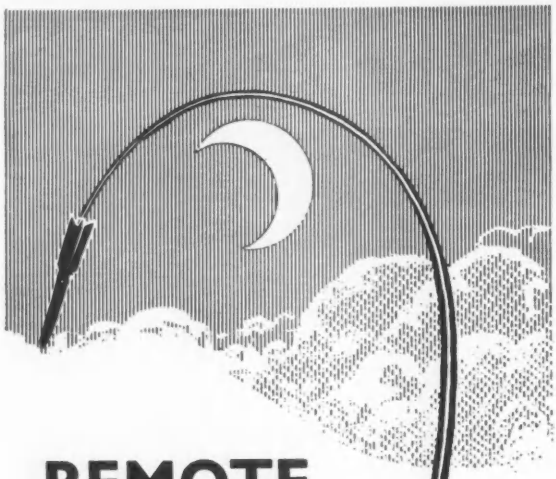

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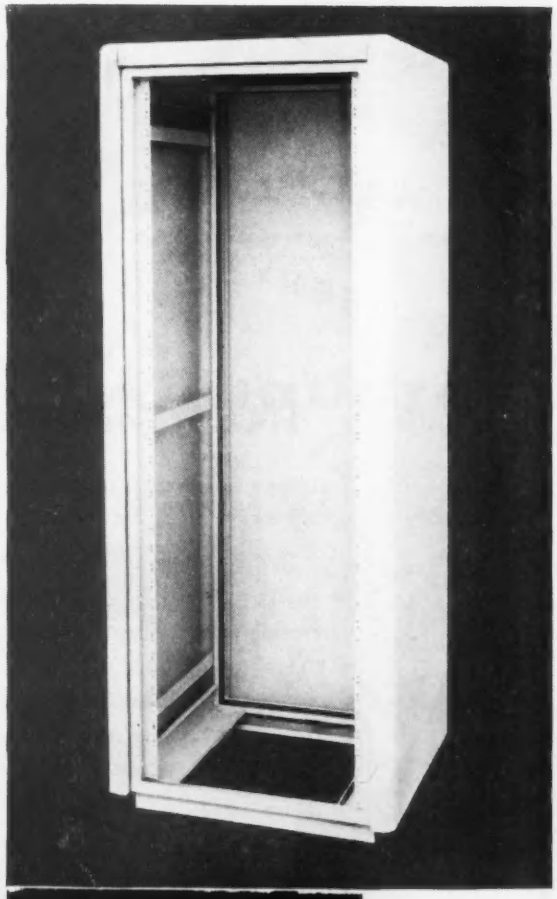
Further details on application to the address below:



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ACTIONATOR

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Features include internal brake and micro switch limit switches.

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Use the powerful new Actionator industrial type motors to operate slip stem valves, rotary plug valves, butterfly valves, dampers, etc.

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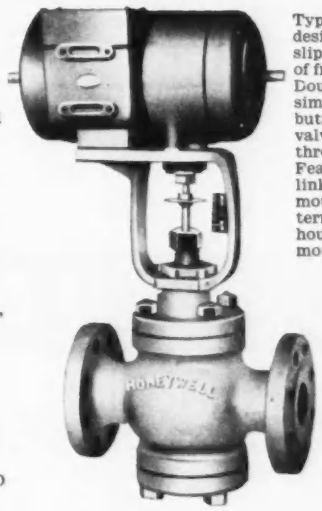

Type B Actionator motors are designed for vertical acting slip stem valves having lifts of from ¼ inch to 1¼ inches. Double ended shaft can also simultaneously operate butterfly valves, rotary stem valves and other devices through suitable linkages. Features include built-in linkage and strain relief, mounting yoke and enclosed terminals with gasketed housing. No auxiliary mounting bracket required.

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SINCE 1885

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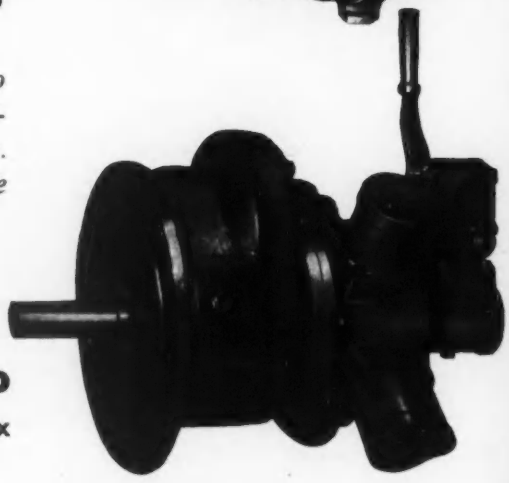

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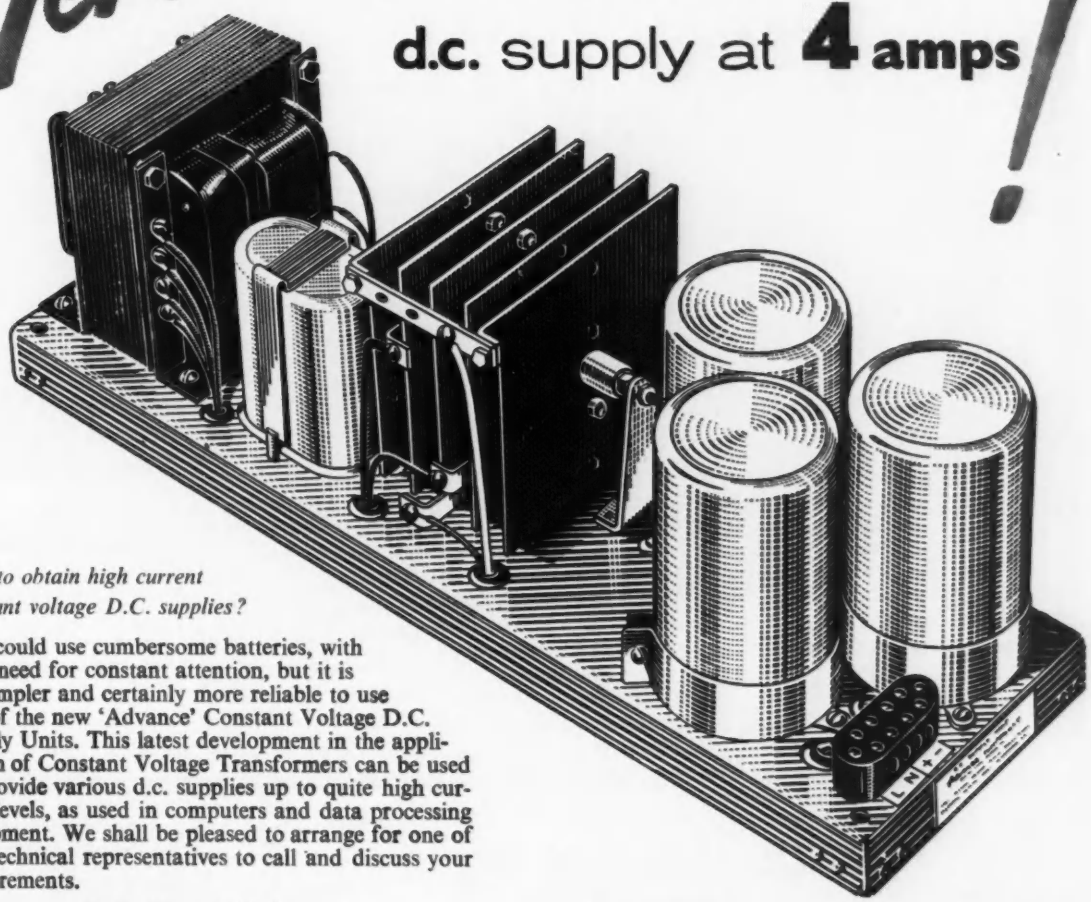

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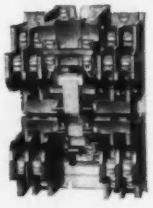
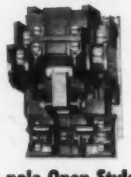
Any pole can be supplied "Normally-open" or "Normally-closed"; double-break main contacts rated at 10-amps. 550-volts maximum. One or two auxiliary change-over contacts can be added in addition to main poles. Tractive coils available—6 to 550-volts A.C.

The relay when open style, is supplied with back fixing plate suitable for mounting on insulation or steel panels, or in metal cases.

4-pole
General Purpose Enclosure



8-pole Open Style
with one auxiliary contact added.



2-pole Open Style
with two auxiliary contacts added.

THE DONOVAN ELECTRICAL CO. LTD.

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TASC unit
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This is what the TASC unit can do

Slash maintenance costs.
Eliminate special precautions against overloads.
Give you local or remote control positively, simply and precisely.
A TASC master (Torque) gives you full control between zero and rated torque.

A TASC master (speed) gives you a 20:1 speed range with good regulation, a smooth and fast take up and no cogging. With full torque available over the entire speed range.
A TASC master (special) can be devised to give you 50:1 speed range.

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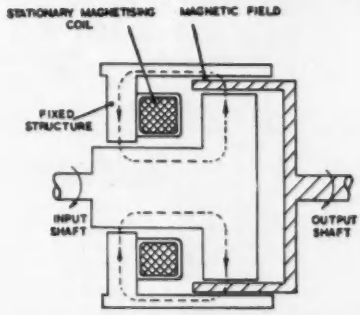

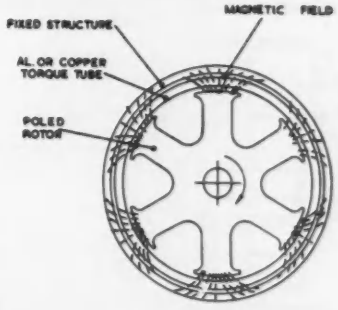

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It consists of two independently rotating members magnetically linked by the field from a fixed coil. The transmitted torque is proportional to the coil current. It is thus an inherently controlled torque device.

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OULTON WORKS, LOWESTOFT, ENGLAND
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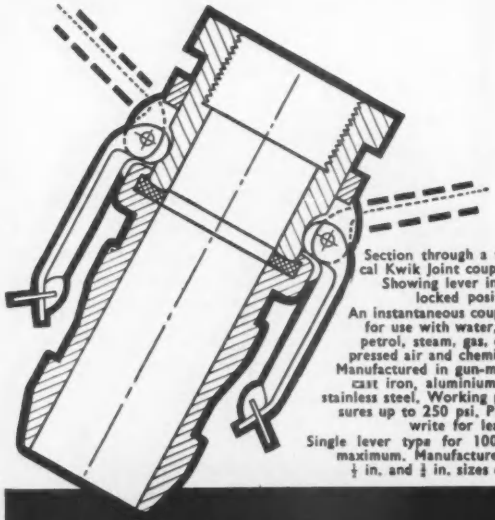

Section through a typical Kwik Joint coupling. Showing lever in unlocked position.

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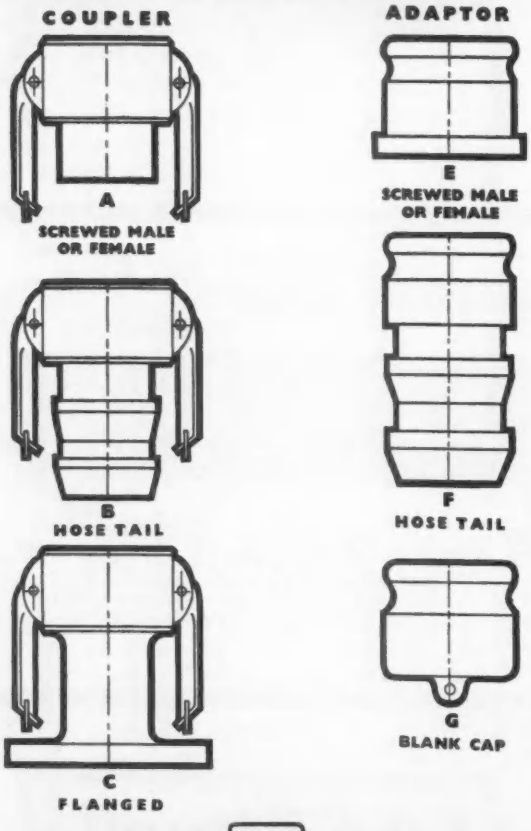

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RESULTS: Improved testing has resulted in "stepped-up" production. Hazardous effects of mercury column indicators have been eliminated.

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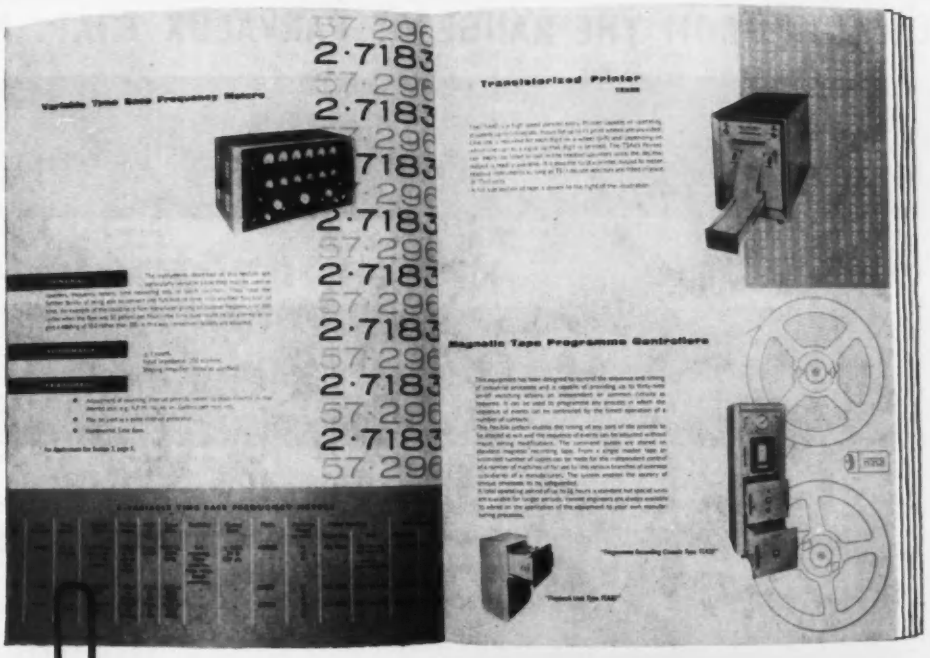

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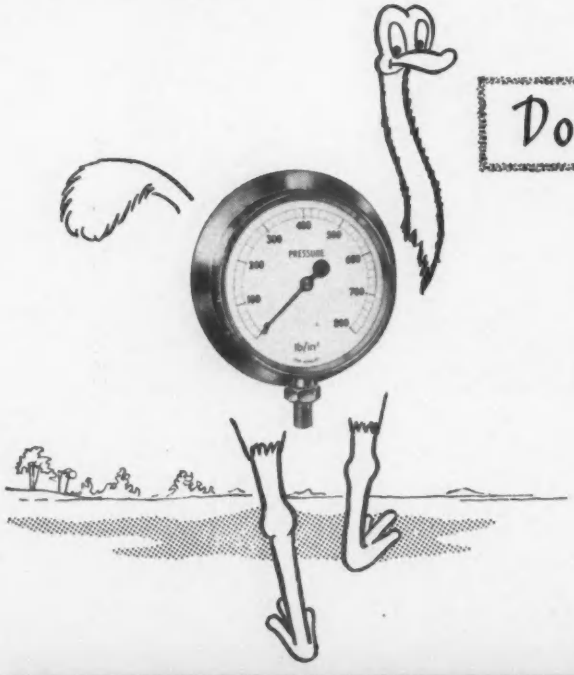

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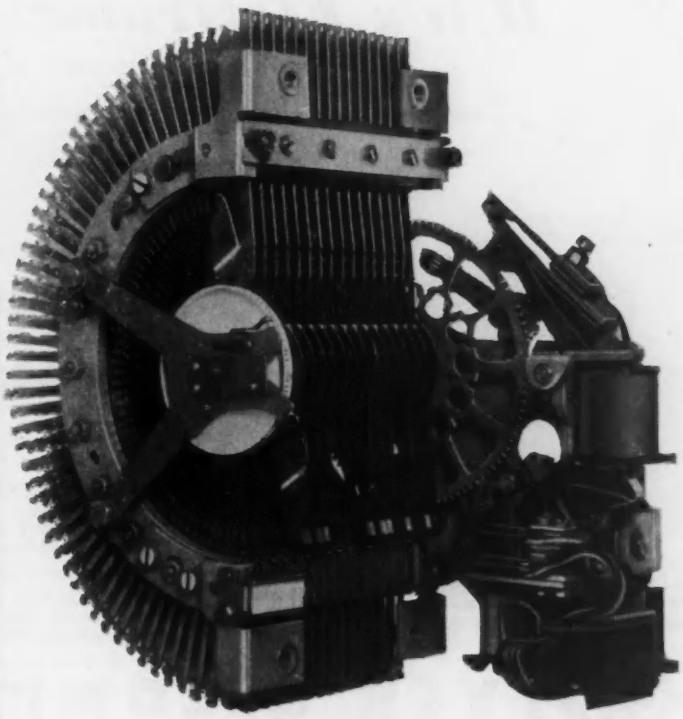
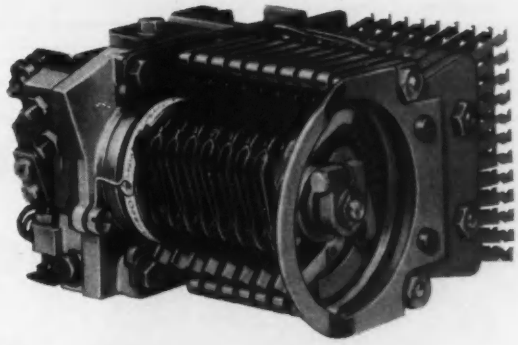
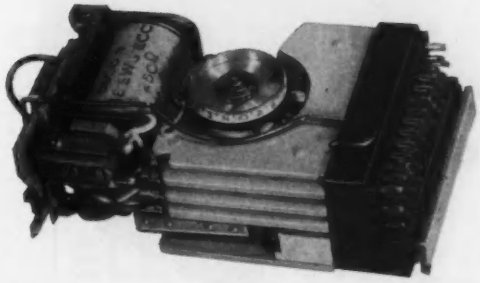


The digit switch
is specifically designed for step-by-step operation in response to impulses, and has an availability of 12 outlets with 8 parallel channels. It may be used to set up a marking condition for the control of the Motor Uniselector.



The miniature uniselector
is a compact switch of unique design which accupies no more space than a standard 3000-type relay. It has an availability of 12 outlets with 3 parallel channels. A great advantage is that it incorporates a plug-in type of mounting so that the entire device can be removed and replaced without detaching any soldered connections.



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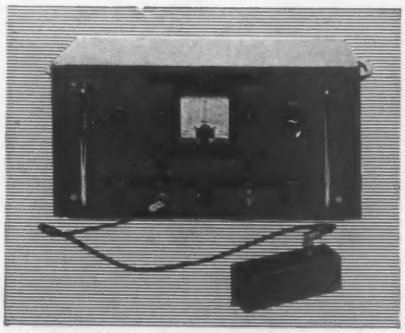

This instrument has been specially designed for the routine production testing of Commutators; its function is to indicate surface roughness and eccentricity to within very close limits.

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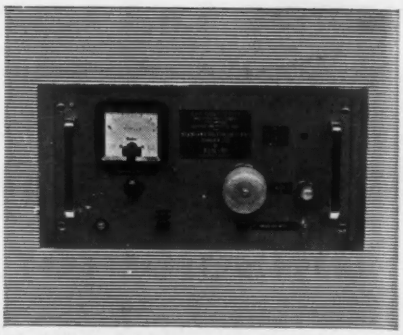

This E.H.T. Cable Insulation Tester has been designed and made by Tyer & Co. Ltd., for detecting and recording faults in the insulating coverings of cables during manufacture. The system permits a very high speed of operation.

Tyer & Co. Ltd. Electronics division combines the technique of several companies, long-established in the Electronic field, with the extensive modern production resources of Tyer & Co Ltd. Examples of recent work are illustrated.

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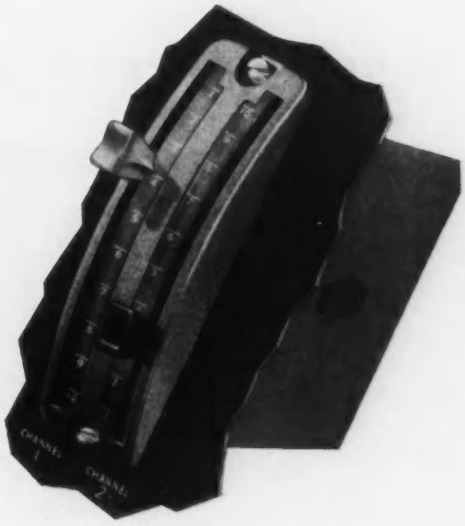

The new ELCOM quadrant instrument offers exciting possibilities to the designer of control desks and equipment.

The instrument houses two individual channels operating separately or ganged and fits into a panel cut-out approximately 5" × 1$\frac{13}{32}$". Eight instruments mounted side by side take up panel space of only 5" × 5½".

The provision of illuminated scales is a feature offered only by the ELCOM quadrant control. Auxiliary switches incorporated in the instrument operate colour changes of this illumination at predetermined positions of the movement of the quadrant arm, thus providing cue lights or warning signals at the actual point of control. For instance, a scale may be illuminated by a green light changing to red when the channel becomes alive. This light change can also be operated from an outside source, e.g. to show when a channel becomes available. The auxiliary switches operate cue lights or signals at other locations.

NOW IN PRODUCTION !

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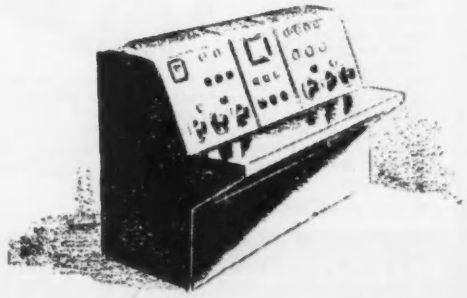

The ELCOM quadrant instrument has an application on every control desk or panel and full information will be given on request.

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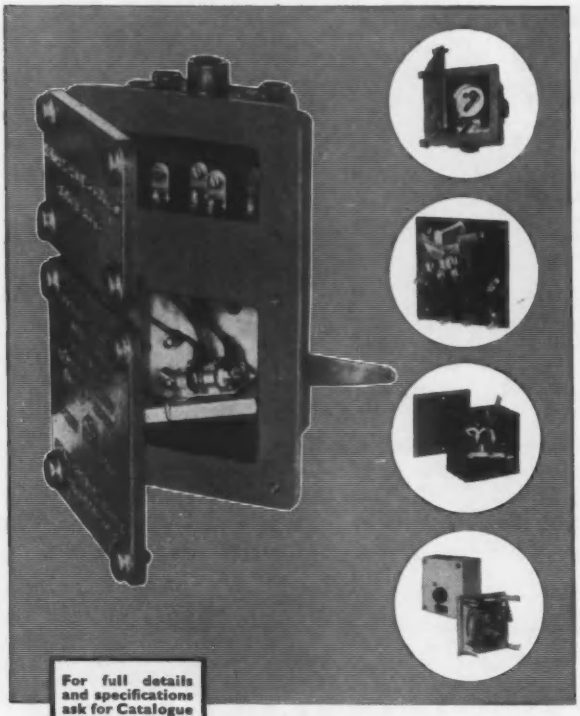
Switches

for special purposes



For full details and specifications ask for Catalogue Sheets

D2 - D6

inclusive.

These special switches are designed to cover a wide range of applications and to cater for exacting duties in industrial processes, including inflammable, corrosive and humid atmospheres.

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A20/FP	Flameproof Mercury Limit Switch	D2
D.2340	Vibration Switch	D3
C.940	Snap-action Mercury Limit Switch	D4
WV, WH	Electric Furnace Door Switches	D5
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for accurate temperature measurements

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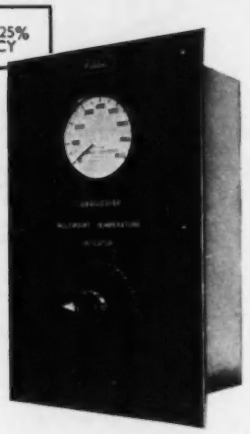

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Write for publications CAP. 1/C, 200/C, and price lists.

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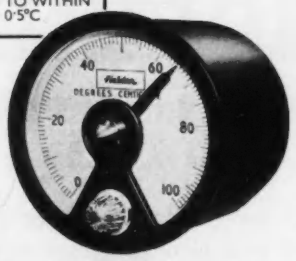

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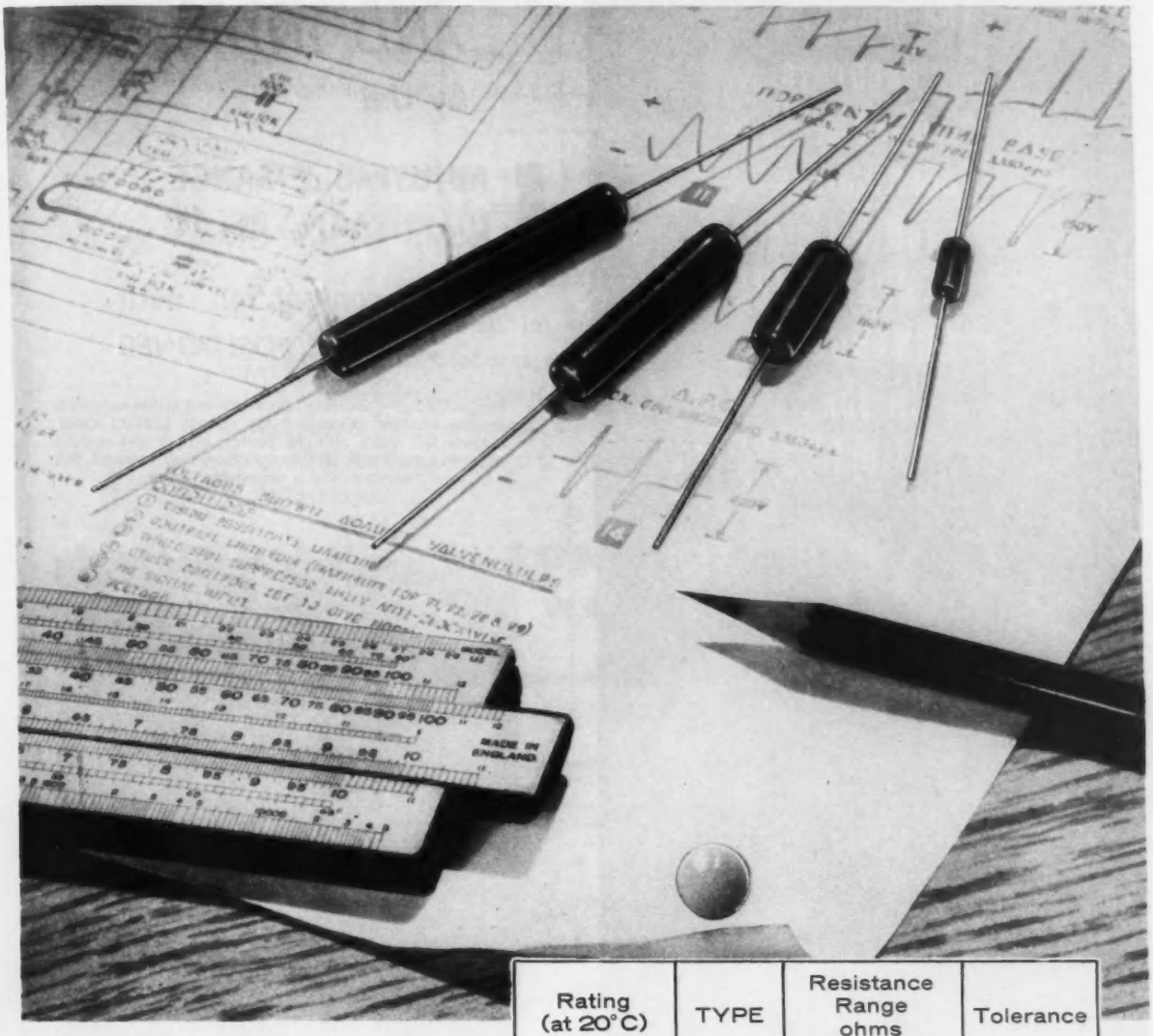
Indicating Recording Control

TEMP/M2

PAINTON Miniature Vitreous Wirewound Resistors



Rating (at 20°C) Watts	TYPE	Resistance Range ohms		Tolerance
		Min	Max	
4	MV1A	1 10	9·9 6,800	10% 5%
7	301A	2	68,000	5%
10	302A	4	140,000	5%
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AND INDICATION
by the

ADJUSTABLE RANGE DIAPHRAGM RELAY

in conjunction with
the ***VALVE POSITIONER***

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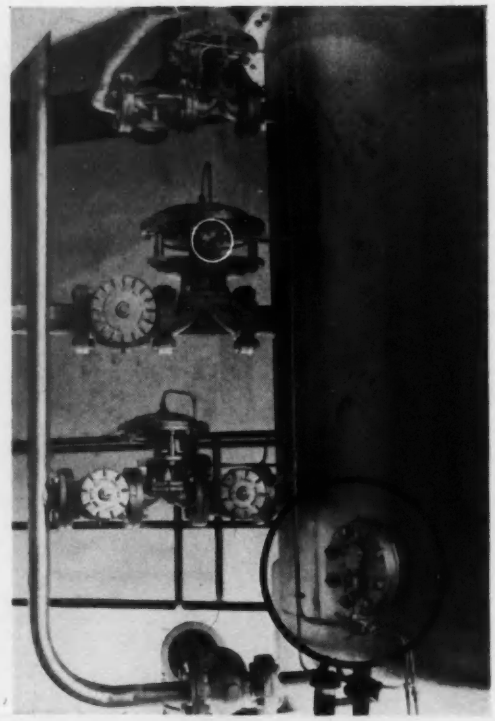

PATENT NO. 679503

White circle indicates Valve Positioner and black circle ARD Relay

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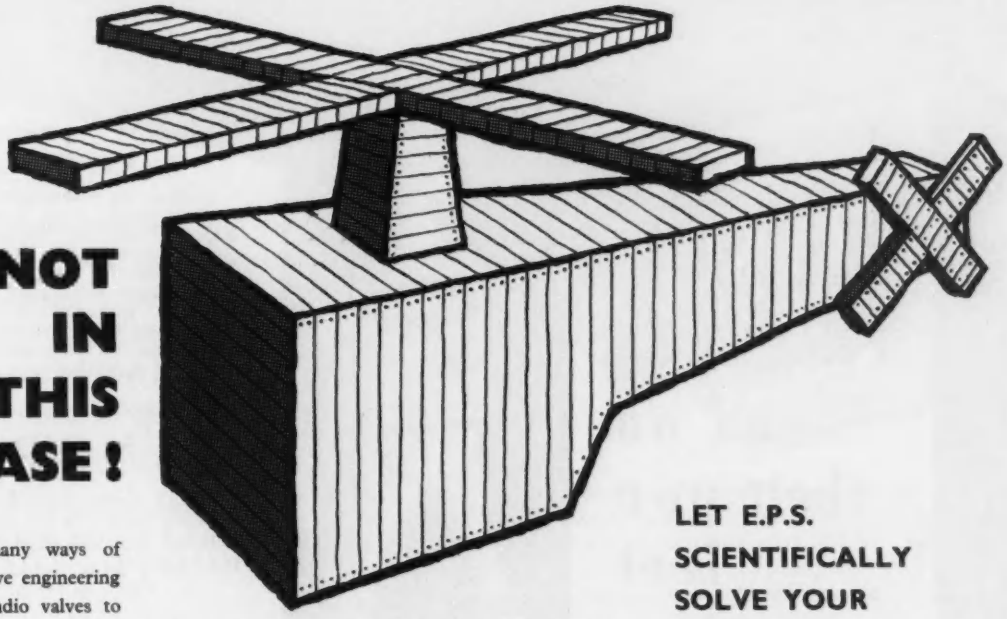

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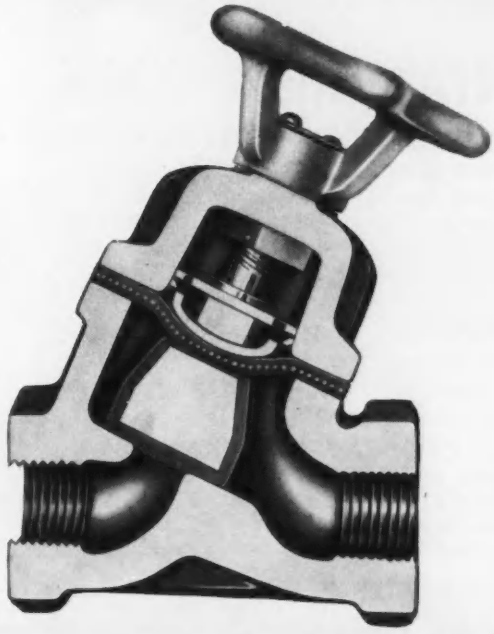

COCKBURNS ROCKWELL

D.D. diaphragm valves

Leak-proof control of Corrosives with positive shut-off

The diaphragm seals gas or fluid within the valve body while the disc ensures positive closure. Losses during operation are prevented and complete safety is ensured with corrosive fluids or gases. Oversize port design greatly increases the capacity of the valve.

Available with or without lining; corrosion resistant union ends allow the lining to come up over the face of the union.

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Cardonald, Glasgow, S.W.1
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MOVING COIL RELAYS

The simplicity and reliability of relay control for a wide variety of applications has led to the ever increasing use of Weston Moving Coil Relays. Let us have a note of your relay problems and we will be pleased to advise on the most suitable model for any set of conditions. Enquiries should, if possible, be accompanied by full particulars of both control and local circuits.

Illustrated is the Model S170. Other types include the Model S124, a magnetic contact relay which operates with a minimum power input of 0.004 microwatt and the Model S115, a miniature relay, which functions as an "on-off" switching relay.

SANGAMO WESTON LIMITED
ENFIELD · MIDDLESEX
Tel: ENField 3434 (6 lines) & 1242 (6 lines) Grams: Sanwest, Enfield

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SW/67

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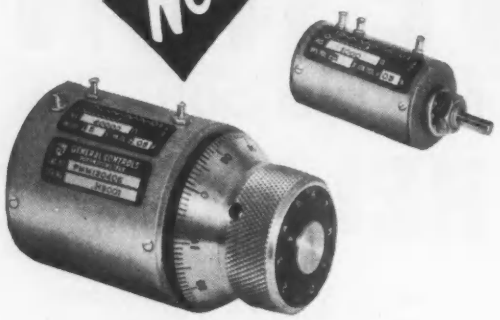

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PRECISION HELICAL POTENTIOMETERS

PK 15 & PM 15 SERIES

of field tested American type Miniature Precision Helical Pots are now manufactured in this Country. DIAMETER only ⅜ in., 10 turn or 3 turn pots available with resistance values of 100-100K ohms.

—WITH BUSH OR SERVO MOUNTING
—BALL OR SLEEVE BEARINGS
—COUNTING DIALS TO SUIT

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are larger types with 1⅛ in. diameter, resistance values 100-500K ohms, 10 turn or 3 turn.

STANDARD RANGE OF COMPONENTS
Standard & Miniature

MINIATURE & STANDARD POTS, WINDOW TYPE DIALS, INDICATING DIALS, FLUSH LOCKS, SPINDLE LOCKING DEVICES and SERVO POTS. SPECIAL WOUND CARDS and POTS to customers' specifications.

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with Resistance tolerance better than 0.1%

Exceptionally compact and light in weight the Type 5206 resistor units of *very high stability* are hermetically sealed in metal cases. Designed for use where resistances up to 10 MΩ are required, the units meet the specifications laid down in R.A.E. Spec. G.1177 and satisfy the tests described in Spec. R.C.S. 11.

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Time constant: Approximately 10^{-6} seconds
Max voltage: 500 V d.c.

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LEARN ABOUT THIS NEW CONCEPTION OF SMOOTH RUNNING . . .

- Even load distribution. Maximum permissible speed $\frac{300{,}000 \text{ r.p.m.}}{\text{shaft dia. mm.}}$
- All needles supplied to a tolerance of ± 0.00004" on diameter.

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Head Office and Factory
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Ina Bearings are manufactured in Great Britain, France and Western Germany.

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FREE

'DIAMOND H' Hermetically Sealed Miniature Relays

For Guided Missiles, High speed aircraft, Computer and other high performance applications

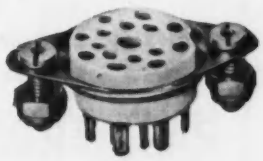
SERIES B R.

HERMETICALLY SEALED 4 P.D.T. RELAYS

Series BR relays are hermetically sealed 4-pole D.T. high performance components. Weighing 4 ozs. or less, they offer vibration resistance better than 2,000 c.p.s. at 20 G, operating shock resistance to 50 G and temperature range from —65° C. to +200° C.
Applications range from guided missiles and high speed aircraft to computers, fire control, radar, etc.

Mounting Arrangements to suit all requirements

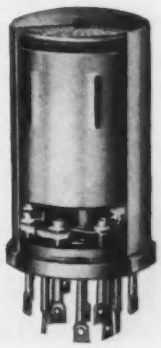
This is one of the wide variety of standard mounting arrangements available for " Diamond H " relays.

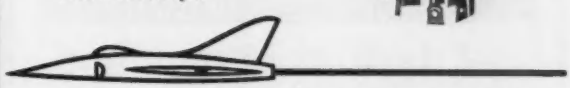


SERIES B S.

HERMETICALLY SEALED 4 P.D.T. RELAYS WITH SEPARATELY SEALED COIL—INORGANIC SWITCH MECHANISM

Greatest dry circuit reliability is assured in series BS relays. by virtue of the coils being separately sealed within the outer hermetically sealed case. The switch mechanism contains no organic matter, hence contact contamination is eliminated. Dry and wet circuits can be safely intermixed. Electrically and physically, series BS relays are interchangeable with series BR relays.





'DIAMOND H' SWITCHES LIMITED.
GUNNERSBURY AVENUE, CHISWICK, LONDON, W.4.
Telephone: CHISWICK 6444 (5 LINES)
Telegrams:– DIAMONHART. CHISK. LONDON.

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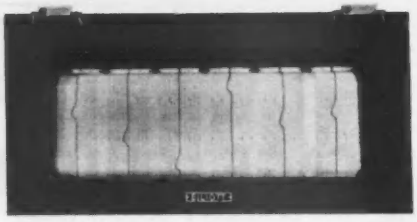
ELLIOTT

Multi-Channel
ELECTRICAL RECORDERS



Elliott Multi-Channel Electrical Recorders will record on from 2 to 6 3-inch wide zones simultaneously. (A.c. or d.c. Values) Polyphase Watt-meter Elements available.
Each movement can be fitted with adjustable high and low level contacts.

Send for publication R.E.4

Electrical Measurement Division
ELLIOTT BROTHERS (LONDON) LTD
Century Works, London, S.E.13 (Tideway 1271)

A member of the Elliott-Automation Group

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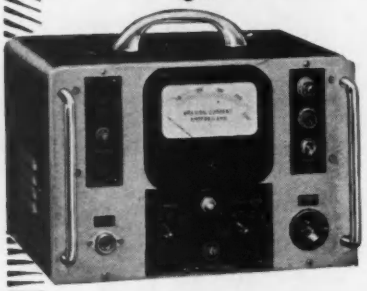
RESISTANCE WELDING CURRENT METER



Designed to measure short pulses of heavy current

The standard instrument has six ranges covering readings of 500 to 100,000 amps. The readings are obtained by the use of toroids which can be split and placed around the heavy current conductor. Indication is stored enabling readings to be taken minutes after the weld is made.

Can be used with welders employing synchronous and non-synchronous and energy storage controls.

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GATWICK ROAD, CRAWLEY, SUSSEX

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SINCE 1880

Makers of Precision Gears

All types up to 8" diameter
10 to 64 D. P.

Send your enquiries to:—

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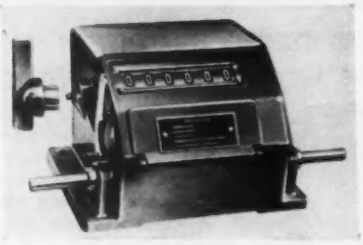
IVO

PREDETERMINED BATCH COUNTERS



IMPULSE
REVOLUTION
STROKE
COUNTING

All types available for :
Electrical or mechanical zero reset.
Predetermination of 1, 2 or 4 independent circuits during single counting process.
Projection or flush mounting.

Also :
PRINTING AND INDICATING COUNTERS
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'Don't blow your top!'

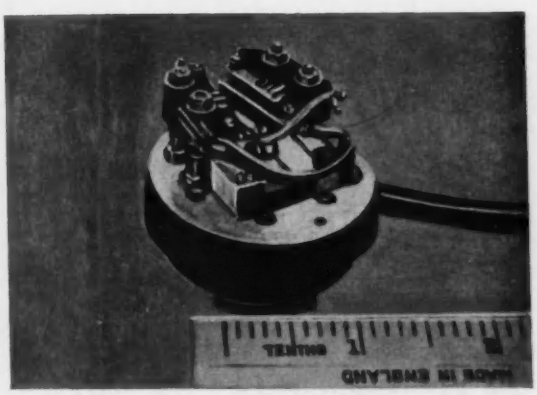
fit an

M.B. METALS

PRESSURE SWITCH

for reliability

This latest addition to the M.B. Metals range of precision control equipment has been designed to meet the stringent requirements of the aircraft and general engineering industries for pneumatic or hydraulic systems.



High accuracy pressure indication at two pre-set levels with a working range of 50 to 6,000 p.s.i.

Specification sheet MPS 200 available on request.

M.B. METALS LTD.

VALE WORKS · PORTSLADE · SUSSEX

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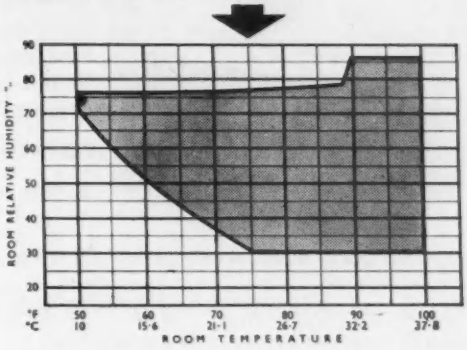
Thermocontrol air-conditioning cabinets

. . . the economic approach to precision humidity and temperature control to any conditions within this area

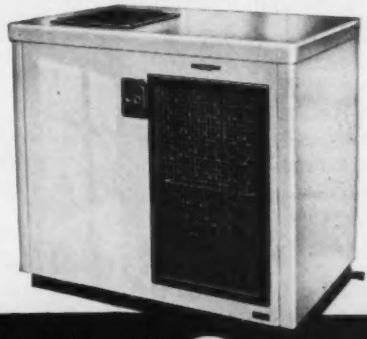


With Air Conditioning Cabinets of the type illustrated, rooms up to 3,000 cubic feet capacity can be conditioned and with agreed installation layouts can be maintained to within ±0·5°F and ±0·75% R.H. settings overall.

The unit is provided with an air outlet raised above bench level and a range of larger units is also available to special design for unusual applications.

The specification of the standard unit includes a replaceable glass-sil filter for air entering the cabinet; centrifugal fan with belt driven fan motor and starter; cooling coil of up to 35,000 B.T.Us. extraction per hour for reduction of either temperature or humidity; air heater with built-in high limit thermostat; room thermostat with relays to operate electric heater when the temperature is low, or cooling coil when the temperature is high; humidistat to control relative humidity through evaporative humidifier.

Our specialist Engineers will be pleased to examine and recommend conditioning equipment for YOUR schemes to ensure maintaining stringent conditions at economic cost.



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automatically first for design • engineering • installation

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CLAMPING TIMES reduced by 30-40%

NEWTON PRODUCT *Hydraulic* CLAMPING

Small diameter Plungers from ½ ton—4 tons pressure

Fast action

Remote control

If you are holding metal, wood, plastic materials, etc. in your manufacturing and assembly processes, you cannot afford not to have a copy of this folder showing many substantial time and money-saving applications.

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GEAR HEADS

MECHANISMS

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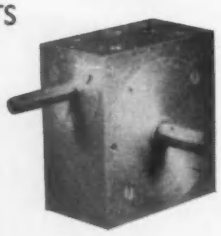

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NORMAL RANGE 24 TO 100 D.P.
IN ANY RECOGNISED MATERIAL

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CONSULT US FOR THE SOLUTION
OF YOUR GEAR PROBLEMS

S. H. Muffett, Ltd.

MOUNT EPHRAIM WORKS
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Tel: HARLOW 24287.
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CRINKLE
SPRING WASHERS
in BERYLLIUM COPPER
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March 1960

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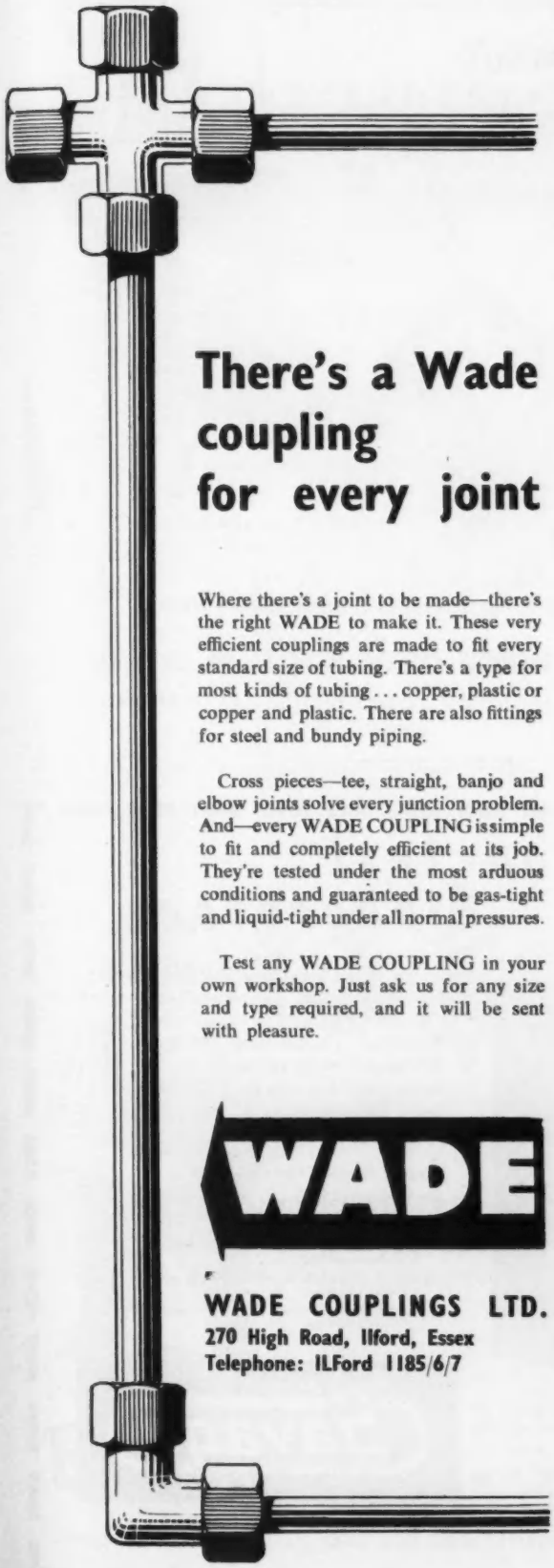

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WADE

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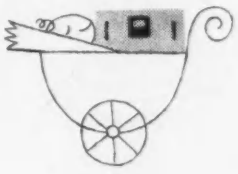
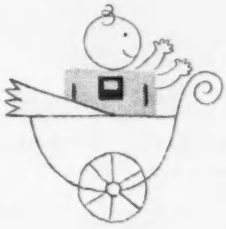
AC STABILIZED POWER UNITS

SMALL SIZE LOW WEIGHT

SILENT AND VIBRATION-LESS



QUICK RESPONSE



GOOD STABILITY

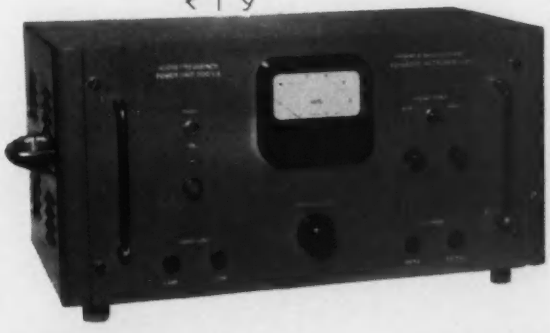
300 C.P.S. to 3 KC. P.S.

To Supply Servo Motors, Magslips, Synchros Amplifiers.

50 V.A. Unit 19" × 3½" × 8" £42

100 V.A. Unit 19" × 3½ × 14" £52

Standard Rack Mounting, Case and Meter Optional Extras. 1, 2 and 3 Phase Units available.



250 V.A. Power Unit Type 250 A1.
Continuously Variable 0 to 120 V
Frequency stability 0.1%
Mains stabilization Ratio 40:1
Adjustable Output impedance + VE to − VE

£125 EX WORKS

ASHGROVE INSTRUMENTS LTD

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A1.1.

England

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HYGROPHIL PSYCHROMETRIC RELATIVE HUMIDITY INSTRUMENT

Employs the same thermo-sensitive elements as the THERMOPHIL Electronic Thermometer. Indicating instrument weighs 15 ozs. and the pistol 26 ozs. The pistol barrel has a diameter of ½" and extension tubes can be added. Battery operated or clockwork fan is employed. Temperature range + 10°F to + 177°F. (– 10°C to + 80°C)

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Telephone: WATerloo 7752/3

vibration test laboratory

Photograph illustrates a corner of our Vibration Test Laboratory

In one of our London factories, we have a completely equipped Vibration Test Laboratory, manned by experienced engineers. The laboratory can accept Vibration work for customers who are unable to carry out their own tests, due either to heavy commitments or equipment not being available.

Range of Vibration Test Equipment

(1) 3,000 lb. thrust vibrator *(Type V1001)* with 10 KW drive amplifier *(Type 10K)* including automatic frequency sweep control *(Type SFO.1)*
(2) 750 lb. thrust vibrator *(Type V1000B)* with 2 KW drive amplifier.
(3) 550 lb. thrust vibrator *(Type V1000)* with 1 KW drive amplifier.
(4) 250 lb. thrust vibrator *(Type V999)* with 500 watt drive amplifier.

designers and manufacturers of vibrators and amplifiers for modern industry

W. BRYAN Savage

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DaS360C

Lock INSTRUMENTATION
NUCLEAR · CHEMICAL · ELECTRONIC

Lock

Portable

CONDUCTIVITY BRIDGE

TYPE BC I

Fully transistorised, it operates at 1500 c/s from a small long-life dry battery. It covers the wide range of 0.5 to 1×10^6 micro mhos in six ranges.

A mains-operated bridge is also available. It covers the range of 0.05 to 1×10^6 micro mhos.

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RELIABILITY... LONG SERVICE... EASE OF MAINTENANCE

Leading design engineers in industries of all types have learned from experience that they can depend on Bailey's pressure regulators to give greater reliability, ease of maintenance and long working life in industrial equipments of all descriptions. By incorporating Bailey's valves in the plant you are designing or producing you will give your products an additional selling advantage.

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In addition to producing a wide range of pressure regulators for controlling steam, air, water, gases and oil, Bailey's offer a complete advisory service on medium and low pressure applications. They will gladly advise on any installation and can supply most of the ancillary components you will require.

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PRESSURE REGULATORS · PARALLEL SLIDE VALVES · SLUICE VALVES · TEST PUMPS

TGA RV13A

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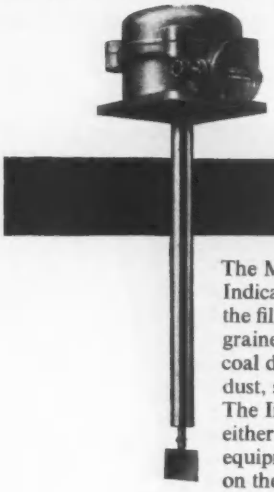

AUTOMATIC BUNKER LEVEL CONTROL

MAIHAK

The Maihak Bunker Level Indicator automatically controls the filling level of fine and coarse grained bulk mass such as coal, coal dust, grain, plant husks, sawdust, soap flakes, dried milk, etc. The Indicator can be fitted with either acoustic or visual signal equipment and the Maihak switch on the paddle operates, if required, the control pump or conveyor carrying the material to the Bunker.

Complete details available from Sole Sales and Service Representatives in Gt. Britain and Ireland.

MAIHAK

SMAIL SONS & CO. LTD.

21/23 INDIA STREET, GLASGOW, C.3

Telephone: CITy 3301 Telegrams: "STEAM" GLASGOW

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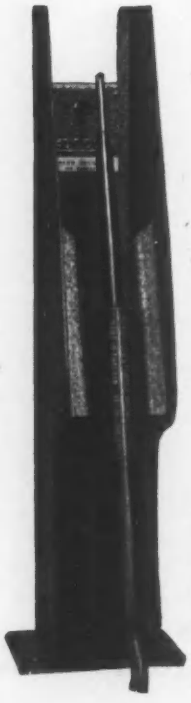
THE ELECTRONIC INDUSTRIES SOLDERING TOOL FOR THE TRANSISTOR AGE etc.

ADCOLA

(Regd. Trade Mark)



¼ BIT MODEL (Cat. No. 70)

PROTECTIVE SHIELD (Cat. No. 68)

ELECTRIC SOLDERING EQUIPMENT

Manufactured in all Volt Ranges from 6/7 to 230/50 Volt with elements Insulated from Earth

A PRODUCT FOR PRODUCTION

Designed for continual use on bench line assembly

BRIT. FOREIGN PATS. AND REG. DESIGNS ETC. Standards approved in all leading countries

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ADCOLA Products Ltd
GAUDEN ROAD
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LONDON SW4

Telephones

MACaulay 3101 & 4272

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Type LP 2

PENNY & GILES

MUDEFORD · CHRISTCHURCH · HANTS
TELEPHONE HIGHCLIFFE 2855

RECTILINEAR POTENTIOMETERS

FOR REMOTE INDICATION AND RECORDING OF DISPLACEMENT

STROKE LENGTHS

Up to 9 inch for Type LP 2
Up to 24 inch for Type LP 1

TWO RESISTANCE ELEMENTS

AMBIENT TEMPERATURES

Available for use in the following ranges
−50°C to + 85°C
−50°C to +150°C
−50°C to +250°C

RESOLUTION of 0·001 inch can be achieved

WRITE FOR DATA SHEETS

Also manufacturers of potentiometers in size 11 and size 15 synchro mountings.
Single and multi-gang. Single and multi-turn.

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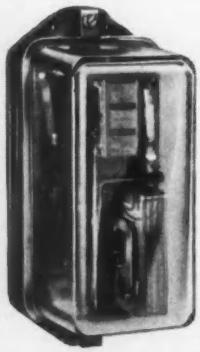
JM

JOHN MORRIS

ELECTRICAL ENGINEERING CO. LTD.
BILSTON TEL. 41237-8 STAFFS

CONTROL RELAYS



★ A new mechanism styled to accept the most up-to-date, precision made, positive self starting, Swiss made Relhor Timing Mechanism.

★ Patented, double break, contact action.

★ Generous tracking distances with fully moulded, non-hygroscopic insulation.

★ Time delayed pick up or drop off.

ASK FOR LEAFLET CR150453

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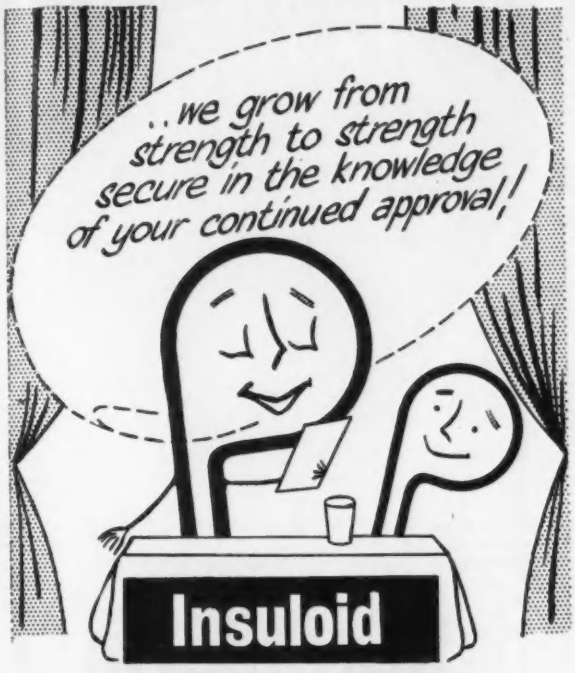

cable clips

. . . the continued approval of manufacturers all over the world is clearly apparent, for every year more and more millions of NX, CY and X type clips are supplied all over the world to Radio, Electronic, Switchgear, Domestic Appliances, Aircraft, Marine Engineering, Atomic Energy, Electrical Contracting and Laboratory Equipment manufacturing industries.

In fact, wherever a high grade and secure fixing is required for cable, tubes or components whatever the climatic conditions.

NX CLIP

Made from the highest grade nylon, stronger than metal and twice as light, in sizes ¼ in. to 1 in. inside diameters.

CY CLIP

For dual cable runs in seventeen sizes, covering cable diameters ⅛ in. up to ⅜ in. In highest grade hard P.V.C.

X CLIP

Manufactured in highest grade hard P.V.C. in twenty-five different sizes from ¼ in. inside diameter to 2 in. inside diameter to cover the smallest and largest wiring runs.

HEAR! HEAR!

Insuloid RING LOCK BUSH

Here's a bush specially designed for instant assembly. The Insuloid simple snap-on finger action is as quick as a thought and once it's fixed it stays fixed, guaranteeing no chafing, and no tools are required whatsoever. Insuloid Ring Lock Bush is non-metallic, fully tropical, high dielectric, is approved by all services and is completely secure under all working conditions. Another Insuloid time-and-money-saving component.

Send for fully descriptive literature covering a full range of Insuloid Cable Clips and Ring Lock Bushes today.

INSULOID MANUFACTURING CO. LTD.
Sharston Works, Leaston Avenue, Wythenshawe, Manchester. Tel.: WYT 2842 & 3163

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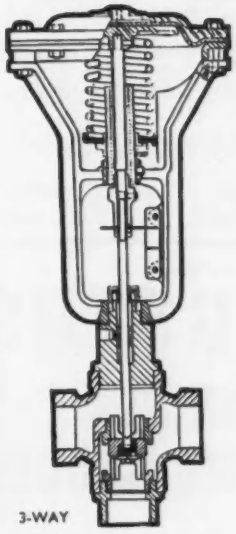
Chemical attack in Process Plant

Small section Iron and Steel castings are extremely expensive relative to their weight and greatly inflate the cost of process valves working on applications where "All Iron & Steel" is specified.

General Specification :



3-WAY

Body
Ductile Iron

Stem
Stainless Steel

Seats
Nickloy, Monel or Stainless Steel

Packing
Fluon

Return Spring
Vanadium Chrome Steel

Hunt & Mitton have pioneered the application of Ductile Iron to control valves for pressure ratings up to 600 p.s.i. at 400°F. Physical properties are akin to steel and the material is equally resistant to chemical attack. Cost is considerably more economical.

Many hundreds of these valves are operating satisfactorily in actual installations at home and abroad.

HUNT & MITTON LTD

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Telephone: MID 0393. Telegrams: Mitton, Birmingham 1

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TEST SIEVES
For Accuracy!

POCKET INTERCHANGER SIEVES

'ENDROCK' TEST SIEVE SHAKER

TEST SIEVES
B.S. 410: 43 U.S. Standards and Tyler Equivalents

We operate a Recovering Service

Consistent mechanical action — saves valuable time of skilled personnel

ENDECOTTS (FILTERS) LTD. Phone: LIBerty 8121/2/3
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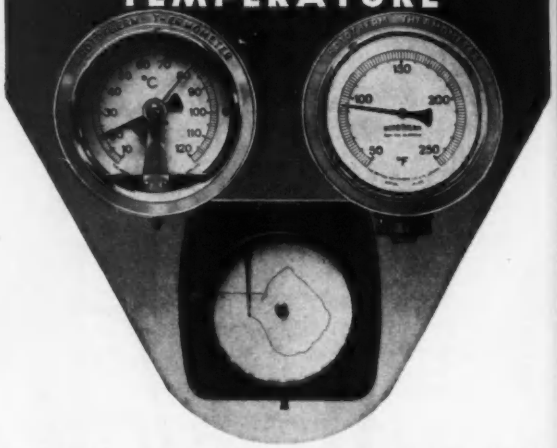
TO INDICATE CONTROL OR RECORD
TEMPERATURE



For accuracy, ease of reading, robustness, economy and long, trouble free life install Rototherm Thermometers, Controllers and Recorders. Specialists in bi-metallic applications.
Write for details.

Rototherm

BI-METAL MERCURY-IN-STEEL VAPOUR PRESSURE
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Midland Factor7: Hollis St., New Basford Nottingham 7784

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RELAY USERS
"CORREX" TENSION GAUGES

The only instrument solely designed for accurately measuring tension on *Relays*, *Contacts*, *Switchgear*, and electrical apparatus of all kinds. Gauge measures in grammes, and a large range of sizes is produced to cover from 0.3–2,000 grammes.
Swiss made and guaranteed.

Write for illustrations and prices from the Distributors throughout the U.K.

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Telephone TERMINUS 8866 (P.B.X.)

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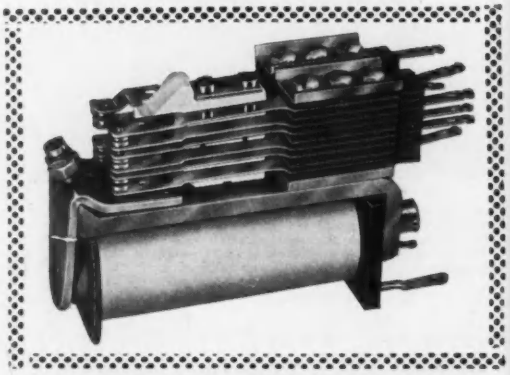
RELAYS
TO SPECIFICATION



POST OFFICE TYPE
3,000 and 600 RELAYS

Specialists in tropical and Services jungle finish.
Guaranteed to full A.I.D. and I.E.M.E. standards.

Prompt Deliveries. Prototypes within 24 hours.

Approved by the Admiralty, Post Office and U.K.A.E.A. All relays guaranteed made in our own works. P.T.F.E. insulation now available

SIMMONDS

Manufacturers to H.M. Government Departments and leading Contractors
L. E. SIMMONDS LIMITED, BYRON ROAD, HARROW, MIDDX.
TELEPHONE: HARROW 7797/9 TELEGRAMS: SIMRELAY HARROW

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SENSITIVITY PLUS!!!

The Type 'R' Switch is adjustable to trip at any point in the range 0-2" w.g. and in the standard form can be used as a pressure, suction or differential pressure switch. The electrical capacity is 5/2 amps at 240/440 volts A.C. S.P.D.T., and the differential is better than 0.1" w.g.

The instrument is designed for panel or wall mounting, and is supplied complete with a short length of flexible conduit for direct connection to a conduit box.

Available either in industrial dustproof case, in a weatherproof housing, or in a Buxton Certified Flameproof enclosure.

Other models cover the range up to 10 tons per square inch.

DELTA Technical Services Ltd.

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Telephone: KINgston 9568 (3 lines)

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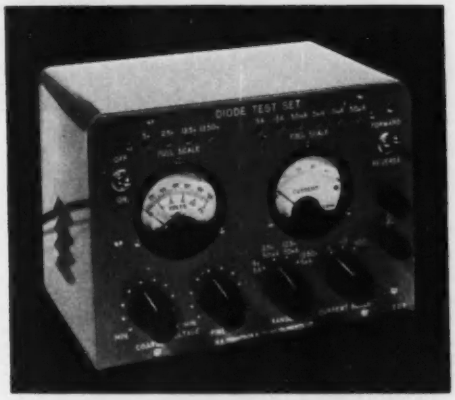
This is it!



AT LAST, a sensible Diode Tester at a sensible price, small yet robust and packed with practical ideas.

* Will test all semi-conductor diodes, including Zener types.
* The diode, once connected, need not be touched until its complete characteristics have been taken.

D.C. RANGES COVERED:

* Current: 5 amps to 50 micro-amps full scale. Voltage: 3 volts to 1200 volts full scale. Four position switches with visible indicator give maximum safety.
* Both voltage and current ranges can be tailored to individual requirements.

'Phone Walton 21302/3 or write for full specifications to

R. E. THOMPSON & CO (*Instruments*) **LTD**

HERSHAM TRADING ESTATE · WALTON-ON-THAMES · SURREY

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ELECTRICAL REMOTE CONTROL CO. LTD.

Manufacturers of Electrical Timing and Control Apparatus

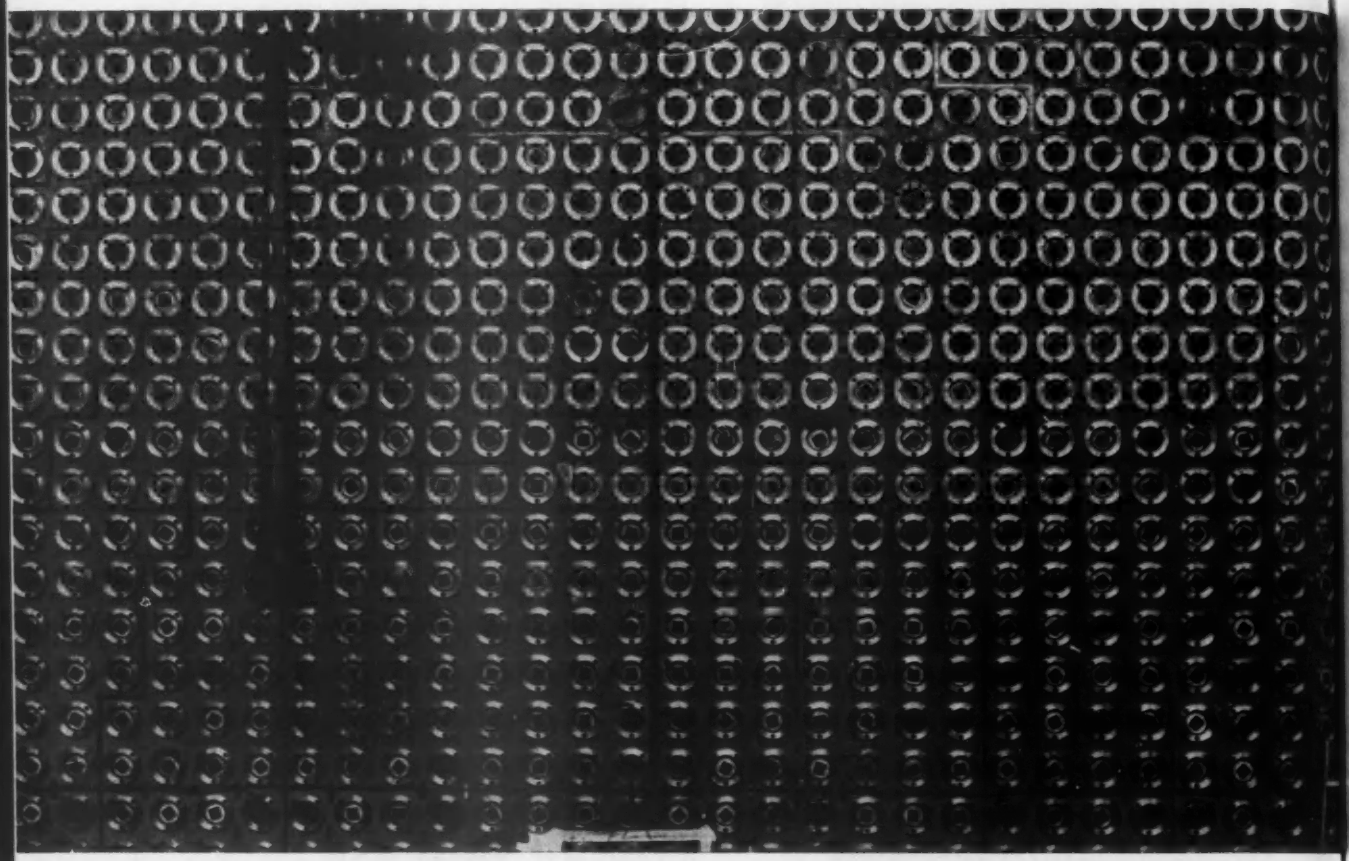
* **Range of fully automatic process timers for AC and DC.**
* **Range of cam operated hand reset process timers for AC and DC.**
* **Multiple contact and mercury relays for AC and DC.**
* **Special purpose control panels to customers' requirements.**

Miniature automatic synchronous timer type ZX 1-12 continuously adjustable independent timing circuits with or without time setting dials. Timing ranges between 0-30 seconds and 0-28 days. Switching capacity 10 amps at 230 v AC. Overall dimensions of 2-circuit unit 2⅜" × 3½" × 5¼"

HARLOW, ESSEX

Tel.: Harlow 24285

A BREAKDOWN HERE COULD COST A FORTUNE



What is the most important piece of machinery in your factory ?

What would be the cost per day to your business if it were to break down ?

It is now possible to cover the loss of profits resulting from such a breakdown as well as the cost of repairing the machine itself.

Policies can be issued to meet the particular requirements of any business.

In this way you can be indemnified against the serious interruptions to your business which can be caused by machinery breakdown.

Should you feel in need of the protection of this new form of insurance we can send an engineer to advise you and inspect your plant.

Write to **D. H. EVERS,** *Industrial insurance consultant*
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1844

The first practical aneroid barometer was invented in 1844 by Lucien Vidie, a French amateur scientist. Since that time the same dial and pointer presentation has persisted despite the disadvantages imposed by the necessity for the aneroid capsule to do work in turning the gears and pointer. In the Mechanism Precision Aneroid Barometer, the aneroid capsule displacement is measured with a micrometer, a scale factor of over 500/1 being achieved with no penalty in work done to overcome friction. This advance is possible, only by detecting with precision the point of contact between micrometer and capsule. Observations of the contact point can be repeated within .00002 inch by incorporating in the contact circuit a 'magic eye' (cathode ray tuning indicator), driven by a self contained D.C. supply. Long term stability is achieved by an extensive process of artificial ageing, independent tests over 15 months showing zero secular drift. Ability to withstand handling shocks has been shown by despatching an instrument by parcel post from Carlisle to Croydon without affecting calibration.

1960

Characteristics :

Ranges	: 800 to 1,050 Mbs.	
	900 to 1,050 Mbs.	
Discrimination	:	± 0.1 Mb.
Accuracy at 20°C	:	± 0.3 Mb.
Accuracy at 0°C & 40°C	:	± 0.5 Mb.

Fitted in Carrying Case :
Weight : 5½ lb.
Dimensions : 6½" × 6½" × 8"

Precision Aneroid Barometer
TYPE M.1847.

MECHANISM LIMITED

GYRO WORKS · GEORGE STREET
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As acknowledged leaders in the automatic resistance welding field, British Federal have a very wide experience of specialised control equipment.

The Company's considerable resources in design manufacture are now available to industry generally, for the production of special purpose electric and electronic control equipment.

This covers the control not only of welding machines, but of motors, machine tools, conveyors and all types of automatic transfer equipment, and it also includes semi-standard panels which can be tailored to suit a wide variety of specific applications.

Type WFO/1. A 3-stage electronic sequence timer available in a wide variety of models and ranges.

Fully synchronous electronic welding control pillar, incorporating phase shift heat control features, synchronous timing and automatic current control with voltage compensation.

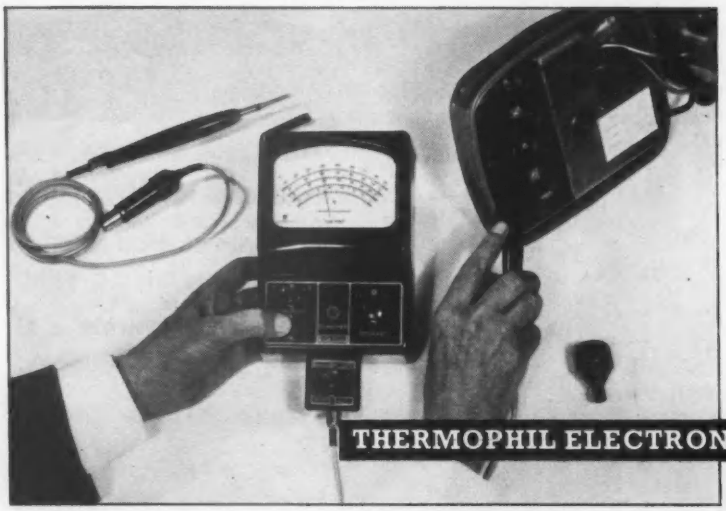
Special high voltage control unit designed and manufactured for a Midland Company and used on Magnet processing.

British Federal

The British Federal Welder and Machine Co. Ltd. manufactures a comprehensive range of welding gear and allied equipment and has considerable experience in applying welding methods to industrial problems.

ALL TYPES RESISTANCE WELDING MACHINES · AUTOMATIC AND MANUAL CONTROL · JIGS, TOOLS AND FIXTURES

BRITISH FEDERAL WELDER & MACHINE CO. LTD. CASTLE MILL WORKS, DUDLEY, WORCS. TELEPHONE DUDLEY 54701



THERMOPHIL ELECTRONIC THERMOMETER

Portable instrument weighing 33 ozs. notable for speed of response, small probe dimensions, and clarity of scaling. Temperature ranges according to instrument types between minus 200°C (—328°F) to 290°C. (554°F).

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Rotameter wish to hear from instrument engineers with experience of technical representation particularly those resident in N.E. England, Scotland or S.W. England. Prime requisites are:—

1. Knowledge and experience of current instrument practice.
2. Chemical plant or refinery experience.
3. Integrity and initiative.

Applications should be addressed to the Sales Manager and marked 'Personal'.

Rotameter Manufacturing Co. Ltd.,
330 Purley Way,
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DEVELOPMENT ENGINEERS

are required by the Hydraulics Division of Fairey Aviation Limited for work on hydraulic and electro-hydraulic servomechanisms, etc. Sound engineering background, logical thinking and perseverence are essential requirements.

Please apply giving full details of experience to the

Personnel Officer,
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SALES ENGINEER and REPRESENTATIVE

To handle complete range of industrial controls for heating, refrigeration and air conditioning of American design. Advantageous if also conversant with precision potentiometers.

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ELLIOTT

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Their work will lie in control systems, engineering and simulation employing the latest concepts of automatic control using analogue and digital circuit elements.

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ELECTRONIC ENGINEERS — **with experience of analogue or digital circuits or closed-loop system development.**

MECHANICAL ENGINEERS — **with a servo background.**

MATHEMATICIANS AND PHYSICISTS — **with a knowledge of servo theory, preferably allied to analogue or digital computer experience.**

ONE PHYSICIST — **is required with a sound background of applied optics.**

A degree, H.N.C. or their equivalent is the minimum qualification for these posts. Salaries are generous, the working atmosphere is congenial and purposeful and the usual social and superannuation benefits are available.

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DUNLOP RUBBER CO. LTD.,
requires a first-class
INSTRUMENT DRAUGHTSMAN

to work in their BIRMINGHAM offices on the design and detail of INSTRUMENTATION/CONTROL SCHEMES for processing plant. An attractive salary will be paid to the person appointed.

Applicants should possess a HIGHER NATIONAL CERTIFICATE (ELECTRICAL OR ELECTRONIC), and have a wide experience of instrumentation, including measurement and control of temperature, flow and pressure.

This post will be pensionable to men under 44 years of age at the time of engagement. Those interested should write in confidence, giving age, experience, commencing salary expected and quoting reference OE/M, to:

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WE SHALL BE PLEASED TO RECEIVE APPLICATIONS FOR THE FOLLOWING POSTS FROM SUITABLY QUALIFIED MEN.

DRAUGHTSMEN
ESTIMATORS
ENGINEERS

O.N.C. (Electrical) is a minimum technical qualification and it is desirable that applicants, particularly for the posts of estimator and engineer, should have had some experience in the motor control gear field.

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RESEARCH ENGINEERS

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Please apply, giving full details of training, qualifications and experience to:—
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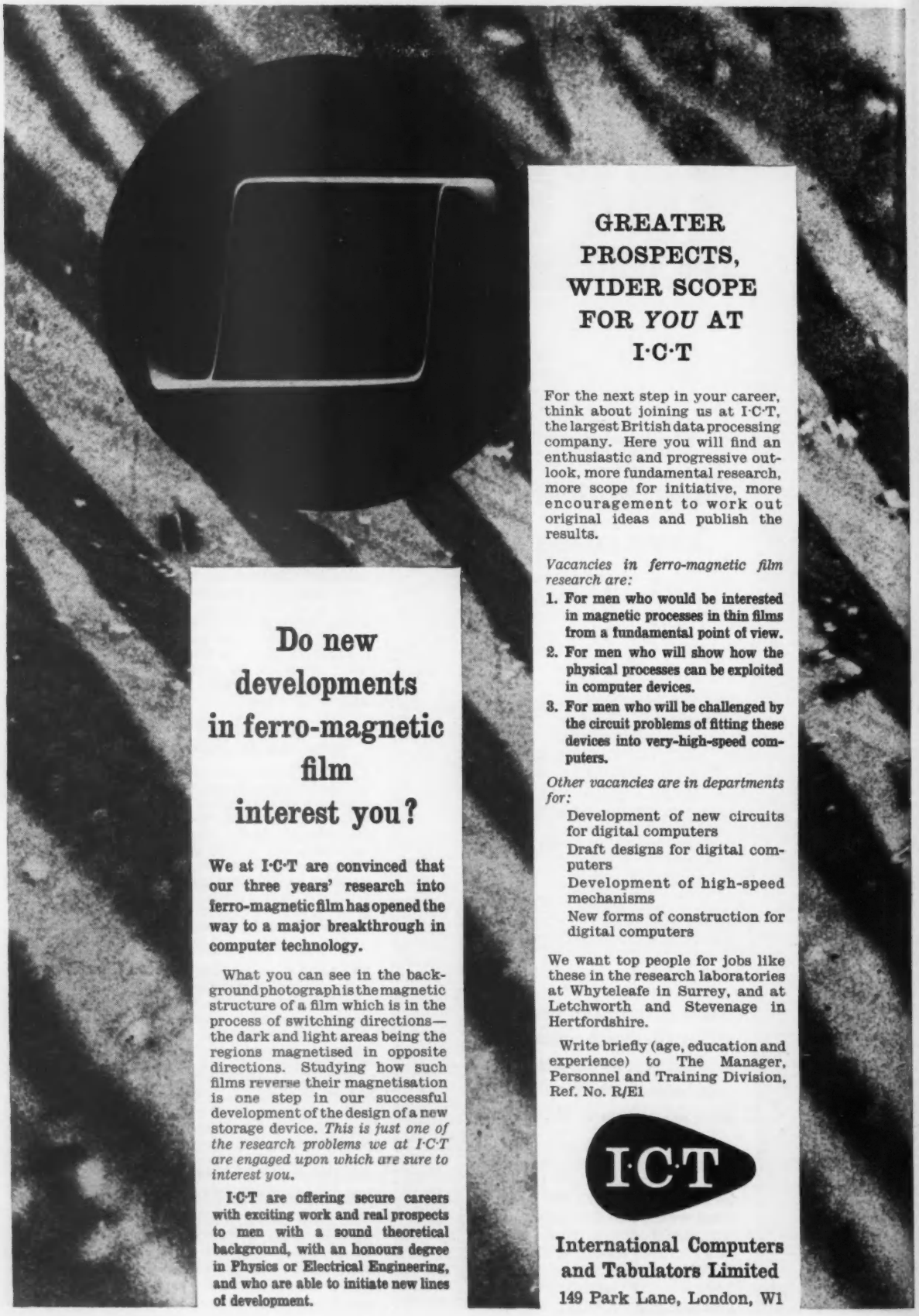

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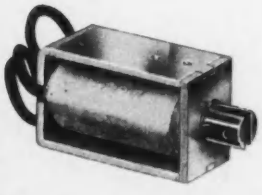

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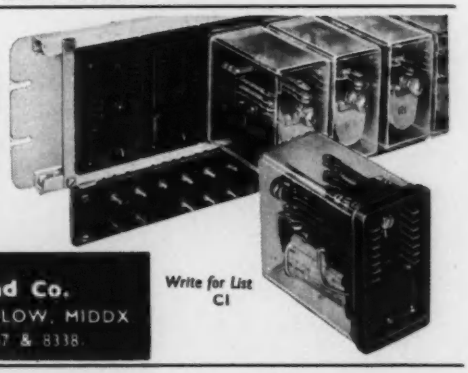

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